GENERAL SCIENCE

GENERAL SCIENCE

BY

I. C. JOSLIN, B.Sc.

LATE HEADMISTRESS OF THE FRANCIS HOLLAND SCHOOL

LONDON
MACMILLAN & CO LTD
NEW YORK · ST MARTIN'S PRESS

M/S. Grantha Sadan
Rs 10.40

First Edition

MACMILLAN AND COMPANY LIMITED
London Bombay Calcutta Madras Melbourne

THE MACMILLAN COMPANY OF CANADA LIMITED
Toronto

ST MARTIN'S PRESS INC
New York

PRINTED IN GREAT BRITAIN

PREFACE

In educational circles at the present time, the view is widely held that the early stages of science courses in schools should be of a general character, in order that pupils should obtain a broad view of science as shown in its many and varied aspects in the world around them. Such courses are of particular value to pupils who do not intend afterwards to specialise in science, but who require a scientific background, so that they have an understanding of the everyday phenomena they continually encounter. Even for the specialist, a preliminary general course is a safeguard against a too narrow specialisation at any early stage.

In the present work, I have attempted to present the subject of General Science in the order in which scientific knowledge has naturally tended to develop. At an early stage of civilisation, men became interested in the sun, the moon, the tides and the passing of the seasons. It is only in recent years that they have come to study the constitution of their own bodies and minds. The general idea of this book has therefore been to start from man as an inhabitant of the earth (the first obvious fact of which he is aware) and then to pass through the various branches of science back to the physiology of man himself. An attempt has been made to keep the subject a living whole, and the sequence is maintained between the various branches by the link from electrons to the chemical composition of matter and from the nitrogen cycle to living matter.

It is possible that criticisms may be made of the proportions of subject matter dealing with the various sciences, but I have been guided not by the relative importance of the sciences but by the extent to which they contribute to man's environment. Since this is the case, such topics as the heating and ventilation

of buildings are as important as the structure of flowering plants, because the average civilised man spends more time within four walls than he does in the fields and hedgerows.

At the same time, much guidance and help has been derived from a provisional syllabus that has been considered by the Science Masters' Association during the last few years. The syllabuses in General Science of the various examining bodies, Oxford, Cambridge, London, the Northern Universities and the Central Welsh Board, have also been given due consideration, and an attempt made to include their requirements in the compass of the book. The selection of examination questions at the end have been printed by kind permission of the various examining bodies concerned.

Certain of the subject matter, in particular the chapters on Air, Water and Heating and Ventilation, have largely been taken from the section of *Everyday Domestic Science*, previously written by me. I should like to thank my collaborator in *Everyday Domestic Science*, Miss Taylor, for her kind permission to use figures 143, 187, and 246, which she specially prepared for that work.

By the courtesy of Messrs. Macmillan & Co. Ltd., I have been able to use illustrations from several of their publications, among them being Stenhouse's *Introductory Biology*, Brimble's *Everyday Botany*, Hadley's *Everyday Physics*, Partington's *Everyday Chemistry* and Parsons' *Everyday Science*.

I welcome the opportunity of expressing my thanks to the authors for these figures, many of which originally appeared in the volumes mentioned.

Throughout its preparation this book has had the supervision and helpful criticism of Sir Richard Gregory, and I most gratefully acknowledge his wise advice and encouragement.

I. C. JOSLIN.

CONTENTS

CHAPTER		PAGE
I.	THE EARTH AND THE SOLAR SYSTEM. GRAVITATIONAL ATTRACTION. TIDES. MASS AND WEIGHT. MEASUREMENT OF TIME - - - - - -	1
II.	FORCE ON THE EARTH. CENTRE OF GRAVITY. SIMPLE MACHINES. WORK. FRICTION. EFFICIENCY. FORMS OF ENERGY - - - - - - -	17
III.	FORMS OF MATTER. DENSITY. PRINCIPLE OF ARCHIMEDES. FLOTATION. FLUID PRESSURE -	33
IV.	HEAT AS ENERGY. EXPANSION. THERMOMETERS. QUANTITY OF HEAT. SPECIFIC HEAT. CHANGE OF STATE - - - - - - - -	50
V.	TRANSFERENCE OF HEAT. VENTILATION AND HEATING OF BUILDINGS - - - - - -	68
VI.	LIGHT AND SOUND PROPAGATION. ECLIPSES. REFLECTION. ECHOES. ACOUSTICS - - -	83
VII.	REFRACTION OF LIGHT. LENSES. CAMERA. EYE. SPECTACLES. COLOUR. RAINBOW - - -	97
VIII.	MAGNETS. MAGNETIC FIELDS. MAGNETIC EFFECT OF ELECTRIC CURRENT. MEASUREMENT OF CURRENT. ELECTRIC MOTOR. OHM'S LAW. PRODUCTION OF CURRENT - - - - -	116
IX.	ELECTRIC POWER. HEATING EFFECT OF CURRENT. DOMESTIC APPLIANCES. HOUSE SUPPLY. LAMPS. ELECTRIC FURNACE. CHEMICAL EFFECT OF CURRENT - - - - - - - - - -	135
X.	STATIC ELECTRICITY. THUNDERSTORMS. PASSAGE OF ELECTRICITY THROUGH GASES. NEON TUBES. ELECTRONS. X-RAYS - - - - - -	148

CHAPTER		PAGE
XI.	Composition of Matter. Mixtures and Compounds. Solutions. Colloids. Osmosis. Capillarity. Surface Tension	161
XII.	The Air	174
XIII.	Water	192
XIV.	Chemical Laws. Symbols. Formulae. Equations	204
XV.	Metals and Ores. Iron and Steel. Coal and Coal Gas. Oils. Limestone. Clays. Sand. Glass	211
XVI.	Acids. Alkalis and Salts. Soap. Chlorine. Bleaching Agents. Disinfectants. Nitrates. Crop Rotation. Nitrogen Cycle	228
XVII.	Non-living and Living Matter. Plant and Animal Life. Nutrition. Respiration. Reproduction. Environment. Heredity and Evolution	243
XVIII.	Flowering Plants	260
XIX.	Flowerless Plants	278
XX.	Life-history and Structure of Amoeba, Hydra, Worm and Insect	290
XXI.	Life-history and Structure of Dogfish, Frog and Fowl	307
XXII.	The Human Being. Hygiene	323
	Examination Questions	343
	Index	355

PLATES IN COLOUR

Figure 223 - - - - - - *Facing p.* 304

Figure 242 - - - - - *Facing p.* 332

CHAPTER I

THE EARTH AND THE SOLAR SYSTEM. GRAVITATIONAL ATTRACTION. TIDES. MASS AND WEIGHT. MEASUREMENT OF TIME

Introduction. From the earliest times, people have looked at their surroundings on the earth, at the sun and the moon and stars in the sky overhead, and, like children of to-day, they have continually asked the question, Why? Their attempts to answer such "Whys" have led to the building up of a vast amount of knowledge about the world in which we live. Thus the curiosity of people about themselves, their surroundings, and the universe as a whole, has resulted in the growth of what we now call **Science.** At first, people were content merely to think about things, or to regard the gods as responsible for every event, and then the advance of knowledge was slow, but once men began to make definite measurements, to do actual experiments, and to think honestly and clearly about their observations, a mass of organised knowledge rapidly accumulated, and modern science had begun its amazing career. Year by year science changes and advances as men continue to measure, to experiment and to think, and year by year they find they have a greater understanding of their environment.

The earth and the solar system. Naturally enough, an early source of wonder to dwellers on the earth was the moving sun, the changing moon and the myriads of stars. To them it seemed that the earth was the centre of the universe, and that these other heavenly bodies moved round it. Then a Polish astronomer, **Copernicus** (1473-1543), published a book in which

he suggested that the Earth and other planets revolved round the sun, while the stars were outside this **Solar System** altogether. When telescopes were invented and improved, it became possible to verify this idea, and **Galileo** (1564-1642) and later astronomers proved it beyond question.

To-day, we know the sun to be a vast mass of flaming, incandescent gases, much hotter than the temperature of any

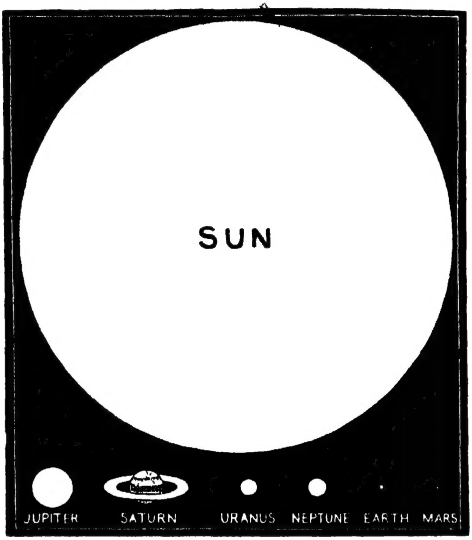


FIG. 1. COMPARATIVE SIZES OF THE SUN AND SOME OF THE PLANETS.

furnace on the earth. The planets rotate round this central sun in almost circular paths, Mercury nearest to the sun, then Venus, the Earth, Mars, Jupiter, Saturn, Uranus, Neptune and finally Pluto, which was only discovered in 1930. They vary in size considerably ; Jupiter is the biggest ; Saturn, Uranus and Neptune also are all much bigger than the Earth, but the others are smaller (Fig. 1). The planets nearest the central sun move most quickly, and by our reckoning of time the Earth makes one complete revolution round the sun in one year,

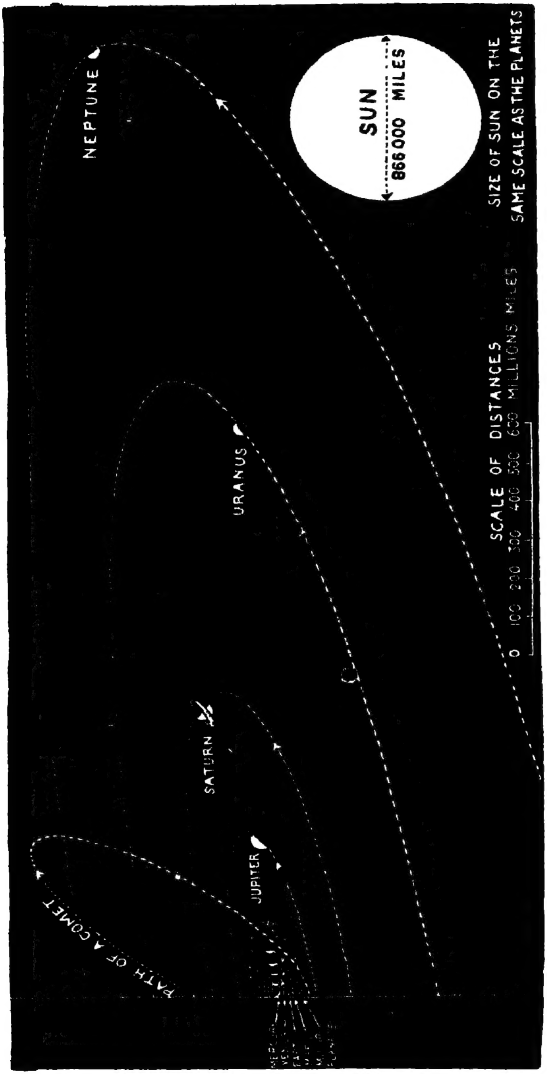

NEPTUNE
URANUS
SATURN
JUPITER
PATH OF A COMET
SUN
866000 MILES
SIZE OF SUN ON THE
SAME SCALE AS THE PLANETS
SCALE OF DISTANCES
0 100 200 300 400 500 600 MILLIONS MILES

FIG. 1A.

Jupiter in nearly twelve years. In addition to motion along this circular path or **orbit**, the Earth rotates on its own axis once in twenty-four hours, so that the side of it facing the sun has daylight, and the side away from it, night.

The actual distances in the solar system are immense compared with the size of the sun and planets. The earth is 93,000,000 miles away from the sun, whereas the distance all round the earth at the equator is only 25,000 miles. If an electric lamp one foot in diameter, like those used for street lighting, is taken to represent the sun, then the earth would be represented by a minute speck of dust more than two miles away from it.

Round most of the planets themselves, smaller satellites or **moons** revolve. Thus our moon revolves round the earth at an average distance of 238,850 miles ; Mars has two satellites, and Jupiter ten, while Saturn has ten satellites and also three flat rings consisting of innumerable solid particles revolving round it. In addition to the planets and their satellites, a certain number of **comets** (Fig. 2) travel round the sun in definite orbits. These objects consist of luminous matter in an attenuated form, and they often show an extended part called the " tail ". **Shooting stars** are small pieces of matter which enter the earth's atmosphere from outer space and become white-hot through friction with the air. Generally they are completely vaporised before striking the earth, but if they are too large for this to happen the **meteor** may reach the earth as a lump of peculiar stony or metallic nature. When they reach the earth in this way they are called **meteorites.**

The stars. The various planets of the solar system have no light of their own, and are only seen because the light of the sun is reflected from them. The myriads of actual stars, however, are like our sun, and they emit their own light, so that they appear as bright points of light. These stars are at much greater distances than the bodies of the solar system. Thus if the rim of a halfpenny be taken to represent the path of the

earth around the sun, the nearest star would be at a point five miles away. So tremendous are the distances in space that it is usual to measure them in **light-years,** that is, *the distance light, travelling at* 186,000 *miles a second, can travel in* 1 *year.* The

=300,000 km. $=9{\cdot}46\times10^{12}$ km.

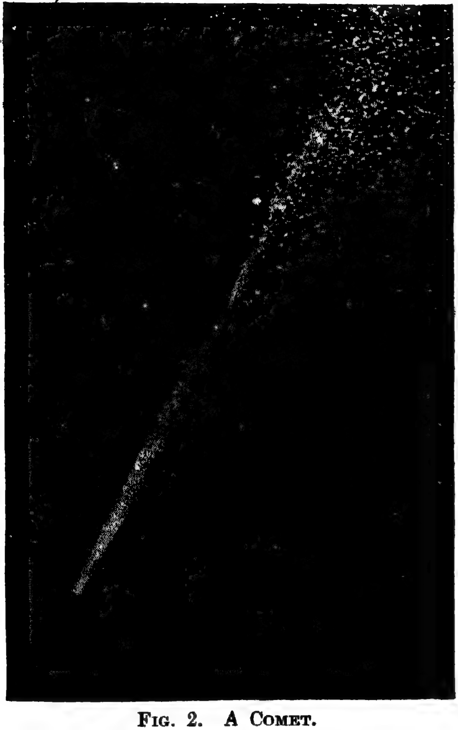


FIG. 2. A COMET.

(By permission of the Astronomer Royal.)

Pole Star, round which the vault of the sky appears to turn, owing to the rotation of the earth, is 30 light-years away, while other stars are thousands or even tens of thousands of light-years away. Most of them appear to be concentrated in the direction of the **Milky Way,** and this suggests that the whole of our universe of stars is shaped like a flattened disc or wheel,

so that we can see more looking towards the rim (that is, in the direction of the Milky Way) than towards the flat sides. Our own sun is not at the centre of this wheel, but perhaps a third of the way from the centre towards the rim.

The stars that appear brightest to us in this great **Galactic Universe** of stars are not always the ones that are nearest. Different stars vary very much in brightness; some are thousands of times brighter than our sun, some thousands of times less bright and there is as much variety as between a glow-worm and a searchlight. Their sizes also vary considerably, and may be likened to the range of sizes from a speck of dust to a lighthouse, but so great is their distance away that even with a powerful telescope they only appear to be bright points of light. They can thus be distinguished from the planets, which do not twinkle like the stars, and are usually seen in telescopes as luminous discs.

In early times men studied the stars, and saw in their arrangement suggestions of the outlines of familiar objects, or they associated them with their legends. So groups or **constellations** came to be called by such names as the Great Bear, the Little Bear (the Pole Star forming the tip of its tail), the Serpent, Orion, Andromeda and so on.

Nebulae. In the two last-named constellations, patches of cloudy luminous material or **nebulae** can be seen with the naked eye, and with a telescope many more can be discovered. Nebulae are of two types; the first, like that in Orion, is irregular in shape, and smoke-like in appearance. It consists of clouds of dust and luminous gas stretching from star to star. The second kind, like that in Andromeda (Fig. 3), is regular in shape and actually consists of a whole new universe of stars comparable to that already described in and around the Milky Way. Hence whole universes of stars like our own exist like floating star-empires far out in space, and the one in Andromeda is 900,000 light-years away, or more than four times farther away than the most distant star of our universe.

FIG. 3. THE GREAT SPIRAL NEBULA IN ANDROMEDA

Gravitational attraction. This latter nebula is spiral in shape, and it is thought to be a system in which stars are being evolved. To begin with, there was a mass of luminous vapour filling all space, and condensations of different parts of this would give rise to nebulae, each of which would have a whirling movement. Gradually the mass of gas cools and condenses and whirls still faster, so that parts of it become detached, but continue to rotate round the central part. The detached parts condense still more, until a planetary system like our own solar system is formed. **Sir Isaac Newton** (1642-1727), a great English

scientist, first showed that the motion of the planets and the movements of all kinds of matter in space are due to the force of **gravitational attraction.** Thus the planets, after becoming detached from the sun, continue to move round it, because of the mutual attraction between them. Sir Isaac Newton is said to have wondered why an apple which he saw fall from a tree should move towards the earth ; it occurred to him that there must be a force attracting it there—the gravitational force of the earth, and reasoning from this he was able to show that the moon moves around the earth because of the same force. The **law of gravitation** discovered by him is that every mass attracts every other mass with a force which increases with their masses but decreases with the square of their distance apart. This variation with distance means that if the distance is doubled, the force is one-quarter ; if the distance is trebled the force is only one-ninth.

In the same way as planets are thought to have been formed by masses whirling off the sun, so, as the planets condensed, pieces were whirled off them to form moons. These moons continued to revolve round their parent planet under the influence of gravitational attraction just as the planets continued round their parent sun.

Tides. It has already been mentioned that the earth has one moon which revolves round it at an average distance of 238,850 miles. The moon is much smaller than the earth and the distance all round it would only be one-quarter of that round the earth. Once in every $27\frac{1}{3}$ days the moon rotates once on its own axis, and also makes one complete revolution in its orbit round the earth. Since these two movements take place in the same time, only one side of the moon is ever seen by us, and so the markings of the mountains and craters always look the same ; the face of the " man in the moon " does not alter (Fig. 4).

This movement of the moon round the earth, and the gravitational attraction between them, causes the heaping-up of the

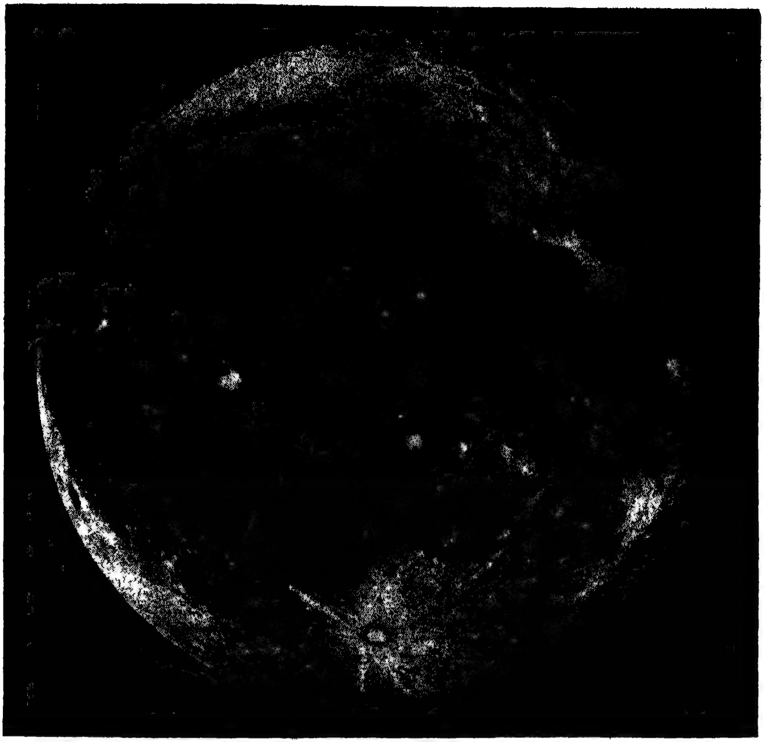


FIG. 4. THE MOON.
(*By courtesy of the Royal Astronomical Society.*)

waters of the seas and the resultant effects of tides. The bulge in the water occurs under the moon and on opposite sides of the earth. As the earth rotates, a place moves towards the position in which the bulge is raised, and **high tide** then occurs at this place. After passing this position, the tide seems to fall or ebb. About twelve hours later the same place experiences a second high tide, because it is in a position where there is a bulge on the other side of the earth.

The sun is immensely more massive than the moon, and might be expected to have more effect on tides, but it is 400 times farther away than the moon, and so its effect is only particularly noticeable when the sun and moon are in line and their combined effect produces particularly high tides called **spring tides** (Fig. 5). At certain times their effects are opposed because their directions are at right angles to each other with respect to the earth; particularly low or **neap tides** then occur (Fig. 6).

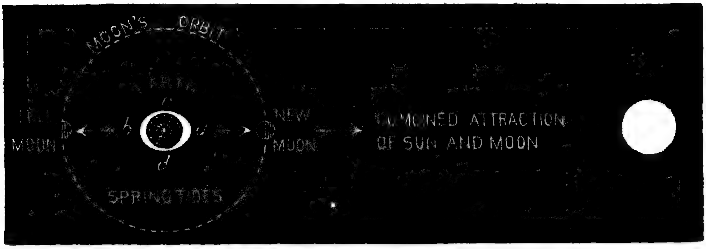


FIG. 5. THE FORMATION OF SPRING TIDES.
The combined gravitational pull of the sun and the moon are in the same direction.

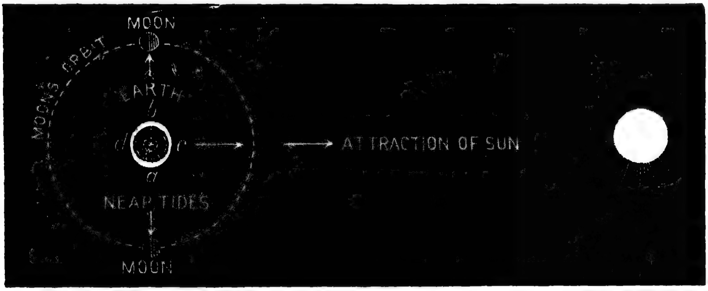


FIG. 6. THE FORMATION OF NEAP TIDES.
The gravitational pull of the moon acts in a direction at right angles to that of the sun.

Mass and weight. The **mass** of an object is the **quantity of matter** it contains. This is not precisely the same thing as its

weight, because mass always remains unchanged, while weight depends on the force of gravitational attraction, which may vary. Thus the **weight** of an object *is the force of attraction between it and the earth.* It has already been seen that this force depends on the masses of the objects concerned and also on their distance apart. Consequently an object taken up in an aeroplane far away from the earth or down a mine nearer to its centre would have a less or a greater weight. The effect of the earth for gravitational attraction is as if its mass were concentrated at its centre, so that even at different places on the earth's surface which are at different distances from the centre (the earth is not a perfect sphere being flatter at the north pole and elevated at the south), the weight of an object may vary slightly. On the moon, which has a mass only one-sixth that of the earth, things would experience so much less attractive force that their weight would seem to be one-sixth of what it is on earth; anyone who could jump a height of four feet on the earth could jump twenty-four feet on the moon.

A measurement of attractive force or weight can be made by observations of the extensions of a spring.

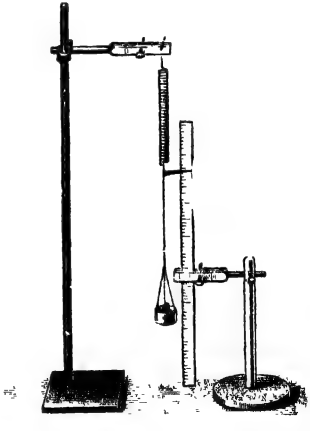


FIG. 7. THE STRETCHING OF A SPIRAL SPRING.

EXPT. 1. **Use of a spring to measure weight.** Suspend a spiral spring from a stand, fixing a needle through its lower end to act as a pointer (Fig. 7). Support a scale vertically by it so that the pointer moves over the graduations of the scale. Read the position of the pointer when the spring is not stretched. Add weights of 10, 20, 30 ... 100 grams and read the position of the pointer in each case.

Tabulate your results thus :

First position of pointer = ... cm.

Weights suspended	Scale readings	Extension
gm.	cm.	cm.
10		
20		

Plot a graph of the extension in cm. and the weight in gm.

Take any small object and find its weight by hanging it from the spring, observing the extension and then making use of the graph.

A **spring balance** (Fig. 8) can be made by having a suitably graduated scale fixed to a spiral spring, and such an instrument is used to measure weight. If the weight varies, the extension of the spring will vary also. In *any given place* on the earth's surface, however, the force acting on a body does not vary and is proportional to its mass ; thus a comparison of weights can be made by comparing masses. The ordinary balance described in the next chapter is used for comparing the mass of an object with a standard mass, but for everyday purposes it is commonly said that this process is " weighing " an object or finding its " weight ". This confusion of terms is of little practical importance (it has just been seen that mass and weight are proportional in a given position) but in science it is often necessary to distinguish clearly between the two terms. Thus a spring balance is used to find the weight of objects, and an ordinary balance to compare masses.

FIG. 8. A SPRING BALANCE.

The units of mass (or in everyday language "weight") are the **pound avoirdupois** on the British system and the **kilogram** on the metric system.

The **Imperial standard pound avoirdupois** is the mass of a piece of platinum weighed *in vacuo* at a temperature of 0° C. This standard is kept at the Board of Trade in London, but a copy of it is kept in the standards office of every city, and the weights used by tradesmen are tested by comparison with it. All weights and weighing machines are supposed to be tested before they are sold, and inspectors of weights and measures visit shops about once a year to check the accuracy of the instruments used for weighing.

The **kilogram** is equivalent to about two and one-fifth British pounds and is determined by the fact that it is one thousand grams, the unit one gram having been taken as the weight of 1 c.c. of water at a temperature of 4° C.

Measurement of time. It has been seen that as the earth rotates on its axis, day and night alternate, and the time taken by the earth to make one complete rotation has come to be regarded as a twenty-four hour day. Actually there is a slight difference in its length according to whether the completion of the rotation is judged by reference to a star or the sun. To an observer in the British Isles, the sun or a star appears to rise on the eastern horizon, to get higher and higher in the sky, and then to sink towards the western horizon, where it sets. When it is at its highest point it is due south. It is then on a vertical plane passing through the North and South Poles of the earth, and this plane is called the *meridian* of the observer. A **sidereal day** is the time between two successive crossings or *transits* of a star across the meridian of the observer. This way of measuring time is useful for the astronomer, but for everyday use, time is reckoned from the sun. Thus a **solar day** is the time between two successive transits of the sun across the meridian of the observer. This varies slightly, because the earth does not travel along its orbit at a uniform rate and so

the average or **mean solar day** is taken as the standard of time for use in ordinary life.

On this latter standard the sidereal day is 23 hours 56 minutes 4 seconds long, and the difference between the solar and the sidereal day is due to the fact that, between two transits of the sun, the earth has moved along its orbit and must complete an extra bit of rotation for the transit to

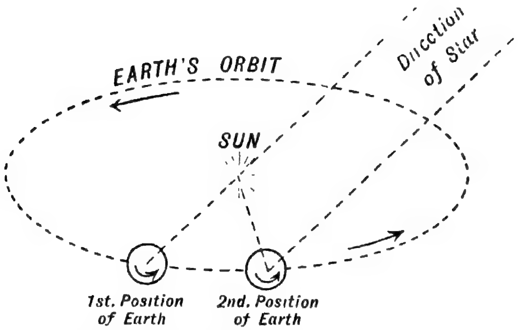


FIG. 9. DIAGRAM TO SHOW WHY THE SOLAR DAY IS LONGER THAN THE SIDEREAL DAY.

take place (Fig. 9). The solar day is therefore longer than the sidereal.

The mean solar day is divided up into 24 hours, 24×60 minutes and $24 \times 60 \times 60$ seconds. The **unit of time** *is the mean solar second.* Clocks measure this mean solar time, but a sun-dial measures the varying solar time. Clocks were invented as the result of experiments by Galileo on the time of swing of a pendulum, the idea for which came to him when he watched a lamp swinging in the cathedral at Pisa.

EXPT. 2. **Time of swing of a simple pendulum.** To a small lead ball, attach a long piece of strong thread. Make a vertical slit in a cork and slip the thread in the slit. Finally, fix the cork in a stand, so that the pendulum can swing freely in front of the bench. Mark a chalk line on the bench, so that transits of the pendulum across the line can readily be observed (Fig. 10). Measure the

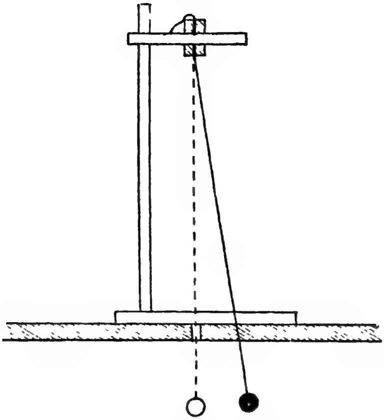


FIG. 10 A SIMPLE PENDULUM.

length of the pendulum from the bottom of the cork to the centre of the bob. Use a watch with a seconds hand to take the time of 20 vibrations (*i.e.* intervals between successive crossings over the chalk line). Alter the length of the pendulum and repeat. Tabulate results thus:

Length	Time of 20 vibrations	Time of 1 vibration	Square of time of vibration
cm.	secs.	secs.	

Plot a graph of the *length* and *time of vibration*; it should be a curve. On the same axes, plot also a graph of *length* and (*time of vibration*)^2. The latter should be a straight line because the quantities are proportional.

Read from the graphs the length of the pendulum required for a time of vibration of 1 second.

The experiment shows that *the length of a simple pendulum is proportional to the square of the time of vibration.* A pendulum

which is a little less than 100 cm., or 1 metre, long, swings once every second, and so conveniently forms a **seconds pendulum.** The length differs slightly, however, in different latitudes. At the equator the length is 99 cm., and in Great Britain at sea level 99.4 cm.

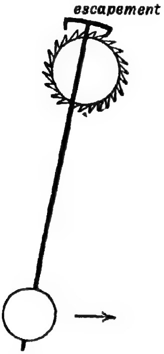


FIG. 11. THE ESCAPEMENT OF THE PENDULUM OF A CLOCK.

Clocks. In everyday life, time is recorded by clocks and watches. A clock contains a pendulum, generally much shorter than a seconds one, and geared by toothed wheels, so that correct time is kept. Some arrangement is needed to keep the pendulum swinging ; there is therefore an **escapement** (Fig. 11), consisting of a crossbar with projections at each end, which engage with the teeth of a toothed wheel. The crossbar is fixed to the pendulum, and every time a tooth escapes from one of the projections, it gives it a slight push, which keeps the pendulum swinging. Thus the time of swing of the pendulum controls the rotation of the wheel. The impulse given to the pendulum, through the action of the escapement, is derived from a falling weight or spring which tends to turn the toothed wheel with which the escapement is engaged.

CHAPTER II

FORCE ON THE EARTH. CENTRE OF GRAVITY. SIMPLE MACHINES. WORK. FRICTION. EFFICIENCY. FORMS OF ENERGY

FORCE

Force on the earth. It has been seen that gravitational attraction is a force acting upon all objects on the earth, whether they are at rest or falling. But other forces as well can be exerted, and unless a thing has life, it remains at rest until a force acts on it. This inability of things to move or change their motion without the action of a force is called **inertia.** Thus a perambulator must be pushed in order to make it move ; once it is moving steadily force must again be exerted to alter its motion and stop it. Both these effects are due to its inertia. It seems, then, that the movement of objects in the world around us is the result of forces acting on them, and **force** may be defined as *that which causes objects to move or to alter the motion they already possess.*

Sometimes there is more than one force acting on a body, and then its motion depends on all the forces. If two people each at a different corner of the same end of a table try to push the table in different directions, the table moves somewhere between the two, as if one force, having the same effect as the two, were moving it there. In other words, the direction of movement is a compromise between the separate directions of the two forces. Every force has magnitude and direction, and it is possible to represent forces by drawing lines of a certain length and direction.

EXPT. 3. **Parallelogram of forces.** Attach three strings to a ring and pass two of them over pulleys fixed to a board (Fig. 12). To these strings attach 100 gm. and 75 gm. weights. Then hang a 125 gm. weight from the bottom string and let the system come to rest. Place a piece of drawing paper against the board and mark the direction of the strings *CA, CB, CR.* Along CA mark off 10 cm. (CE) to represent 100 gm., and along CB 7·5 cm. (CD) to represent 75 gm. Complete the parallelogram CDFE. Join *CF* and measure it. It should be found to be 12·5 cm. long (representing 125 gm.) and be in the same direction as CR.

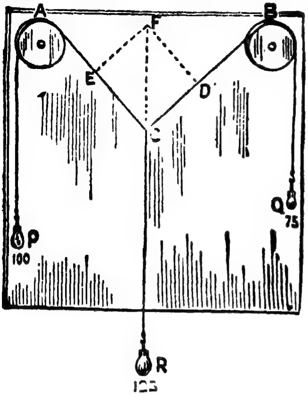


FIG. 12. EXPERIMENT TO ILLUSTRATE THE PARALLELOGRAM OF FORCES.

When two forces act on a body, the effect is as if there were one **resultant force** and the value of this is given by the **parallelogram of forces** which states that *if two forces acting at a point be represented in magnitude and direction by two adjacent sides of a parallelogram, the resultant of the forces is represented by the diagonal of the parallelogram passing through the point.* In the experiment *CF* represented the resultant, and the 125 gm. along *CR* was an **equilibriant** force, that is, one which was equal and opposite to the resultant and therefore balanced it. Since the force represented by CF has precisely the same effect as the forces represented by CE and CD, the latter are said to be the two **components** into which CF can be resolved.

The aeroplane. It will be seen in the next chapter that an airship can fly, because it is lighter than air, but an aeroplane is heavier, and yet the forces on it can act to lift it. The engine drives the propeller, so that the aeroplane travels quickly over the ground and a strong force of the wind pressure acts at right angles to the main wings (Fig. 13). This force can be resolved into two components, one acting horizontally backwards, and one vertically upwards. The pull of the propeller forwards

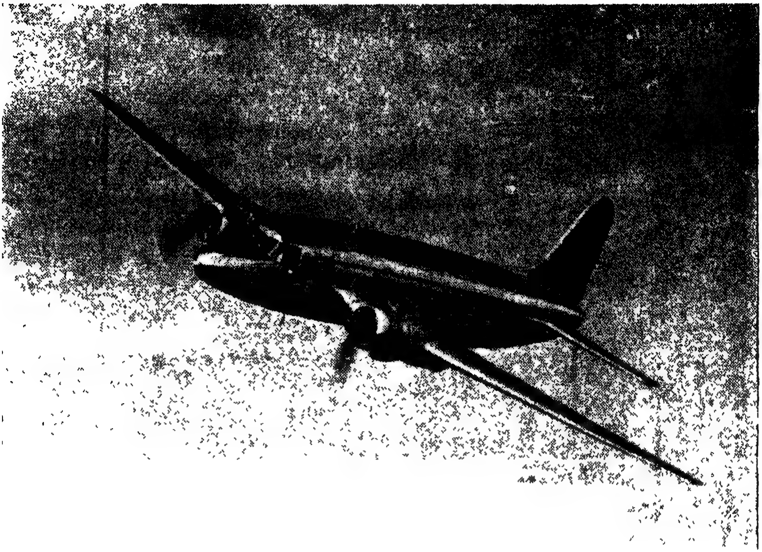


FIG. 13. A VICKERS "VIKING" AEROPLANE.

(By courtesy of Messrs. Vickers-Armstrongs, Ltd.)

overcomes the former, and when the aeroplane is just about to leave the ground the vertical component must be just greater than the weight of the aeroplane, so that it can rise. These forces alone would tend to make it assume a vertical position, so, to prevent this happening, there is a small tail plane also, and the wind pressure on this has similar vertical and horizontal components which keep the tail of the aeroplane up.

Centre of gravity. When a book is dropped, the force acting on it to make it move is that of gravity. Now a force generally acts at a certain point, and although gravity may be acting on all the particles of the book, it may seem to act particularly at one point. To test this, the book may be pushed to the edge of the table till it is just about to fall (Fig. 14); a line is then

drawn across its cover marking the position of the edge of the table. The book is then turned round and again pushed to the edge of the table and a second line is marked. These two lines intersect and if the finger tip is placed at the point the book will balance. It seems as if it is possible to exert an upward force at that point completely to neutralise all the downward force due to gravity. Such a point is called the **centre of gravity** of a body. The point was shown by the intersection of the two lines, because the book must begin to fall when the force of gravity can act at this point beyond the edge of the table, and the point of intersection is the only one where this occurs for both lines.

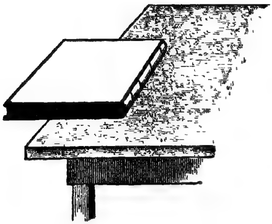


FIG. 14. THE BOOK FALLS WHEN ONE-HALF OF IT PROJECTS BEYOND THE EDGE.

EXPT. 4. **Centre of gravity of a piece of cardboard.** Take an irregularly shaped piece of cardboard ; make a hole near its edge and suspend it by thread from a stand. Hang a plumbline (the pendulum used in a previous experiment will do) so that the thread of it is close to the suspending thread. Draw a vertical line on the cardboard by means of the plumbline. Turn the cardboard round and suspend it from another point, again drawing a vertical line on the cardboard (Fig. 15). The point where the two lines intersect is the centre of gravity. Test if it is correct by trying to balance the cardboard on a pencil point supporting it at the centre of gravity.

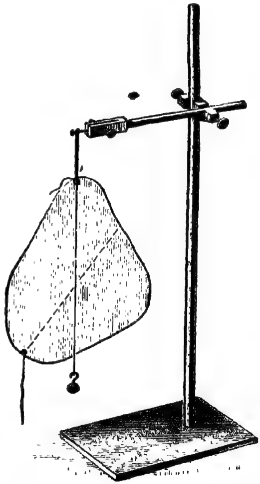


FIG. 15. METHOD OF FINDING THE CENTRE OF GRAVITY OF AN IRREGULAR-SHAPED PIECE OF CARDBOARD.

Stability. The position of the centre of gravity of a body affects its stability. This may be shown by standing a block of wood on a board with a plumbline affixed to the centre of one face and gradually raising the board till the block topples over (Fig. 16). The centre of gravity is right in the middle of the block, but the plumbline is parallel to a vertical line through the centre of gravity and when this line falls outside the base the block topples over.

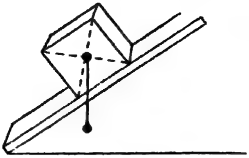


FIG. 16. THE BLOCK TOPPLES OVER WHEN THE PLUMBLINE FALLS OUTSIDE THE BASE.

A famous tower at Pisa, known as the Leaning Tower, has remained standing for centuries because still the vertical line

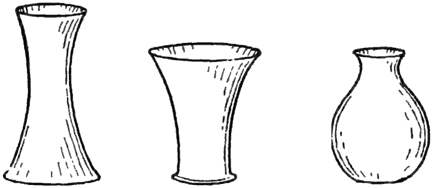


FIG. 17. SOME FLOWER VASES ARE MORE STABLE THAN OTHERS.

through the centre of gravity falls inside the base. A flower vase with a large or heavy base has a low centre of gravity and is less likely to fall over than one with a wide and heavy top (Fig. 17).

SIMPLE MACHINES

Simple machines. In order to exert force on the earth, and make things move easily, machines have been invented. A **simple machine** is an instrument by which force exerted at a certain point and in a certain direction is made available at another point and in another direction. For example, a person exerts force on the handles of a pair of scissors, but the useful

effect of that force is seen by the action of the blades on the material.

The force applied to a machine by the person using it is called the **effort**, and the resistance that has to be overcome by the machine, the **load**. Obviously, the most effective machine is one in which a big load is overcome by a small effort. Perhaps the lid of a packing case is nailed on so that a force of 10 lb. is required to raise it. By using a crowbar, a man may exert an effort of only 1 lb. on the handle and yet overcome the 10 lb. resistance. The crowbar is a simple machine, and since by means of it an effort of 1 lb. overcame a load of 10 lb., it is said to have a **mechanical advantage** of 10. Thus :

$$\textbf{mechanical advantage} = \frac{\textbf{load}}{\textbf{effort}}.$$

The effectiveness of certain types of simple machine. the lever, the winch and the pulley, may be investigated by considering their mechanical advantage.

The lever. The lever is a rigid rod which is free to turn about a point called the **fulcrum**. A very simple example is that of a see-saw, when a child at one end of the plank raises a child at the other end by making the plank turn about a tree trunk. In this case, the weight of the first child represents the effort, that of the second, the load, and the point where the tree trunk supports the plank, the fulcrum. It is possible for load, effort and fulcrum to be arranged in ways other than this : load and effort may both be on the same side of the fulcrum.

For experimental purposes, a simple lever may be made by gripping a metre ruler in a bull-dog clip, and passing a knitting needle through the holes, the needle then being supported in a horizontal position.

Expt. 5. **Mechanical advantage of a simple lever.** Suspend a metre ruler by means of a bull-dog clip and a knitting needle ; if necessary move the clip along so that the ruler hangs freely exactly in a horizontal position. Weigh a scale pan on a spring balance marked in grams ; place a 100 gm. weight in it as load, and suspend

it at a short distance from the middle of the clip (that is, the fulcrum). Hang another scale pan of known weight close to the end of the lever on the other side of the fulcrum and place weights in it until the load is just raised and the ruler balances horizontally again (Fig. 18). Obtain more readings, varying the distance of the load

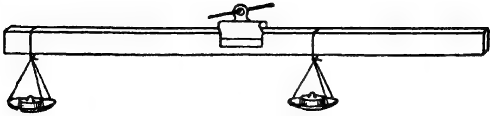


FIG. 18. A SIMPLE LEVER ARRANGED WITH LOAD AND EFFORT ON OPPOSITE SIDES OF THE FULCRUM.

from the fulcrum, but keeping the effort on the same position. Note that the load and effort must include the weight of the respective scale pans. Tabulate results thus :

Distance of effort from fulcrum = ... cm.

Load	Distance of load from fulcrum	Effort	Mechanical advantage
gm.	cm.	gm.	

EXPT. 6. **The law of the lever.** Use the same apparatus, but vary the load and the distance of the effort from the fulcrum. In every case, note the weights used, and the distances from the fulcrum. Readings can be obtained with the load and effort on the same side of the fulcrum if the lever is raised to a horizontal position by means of a spring balance ; the reading of the spring balance measures the effort. Tabulate thus :

Load	Distance of load from fulcrum	Load × distance	Effort	Distance of effort from fulcrum	Effort × distance
gm.	cm.		gm.	cm.	

The principle of the lever. When a given load is placed at different distances from the fulcrum, the farther it is from the fulcrum the less is the mechanical advantage ; in fact, if the load is farther away than the effort, the mechanical advantage may be less than 1. We use this fact unconsciously when we place material to be cut close to the fulcrum, that is, the screw, joining the blades of the scissors, rather than at their points. There is, moreover, some definite connection between the values of the load and effort and their distances from the fulcrum. Experiment shows that the relation is :

$$\text{load} \times \frac{\text{distance of load}}{\text{from fulcrum}} = \text{effort} \times \frac{\text{distance of effort}}{\text{from fulcrum}}.$$

This is the principle of the lever. The explanation of the increased mechanical advantage when the load is near the fulcrum

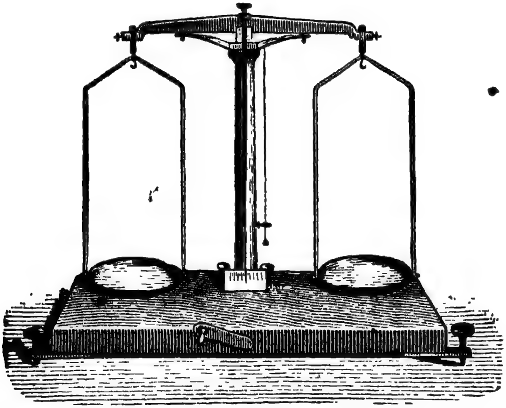


FIG. 19. A STUDENT'S BALANCE FOR WEIGHING THINGS VERY ACCURATELY.

is now obvious ; if the effort is at a much greater distance than the load, the value of the effort need only be small for the two products to be equal.

In the special case when the two distances are equal, the load and effort must be equal for the lever exactly to balance ; this

arrangement forms the balance used for weighing (Fig. 19). If the arms of the balance are of equal length, the known mass placed in one pan must be equal to the unknown mass in the other.

Simple levers in the home. In Fig. 20 are seen some everyday appliances consisting of one or more simple levers. In some

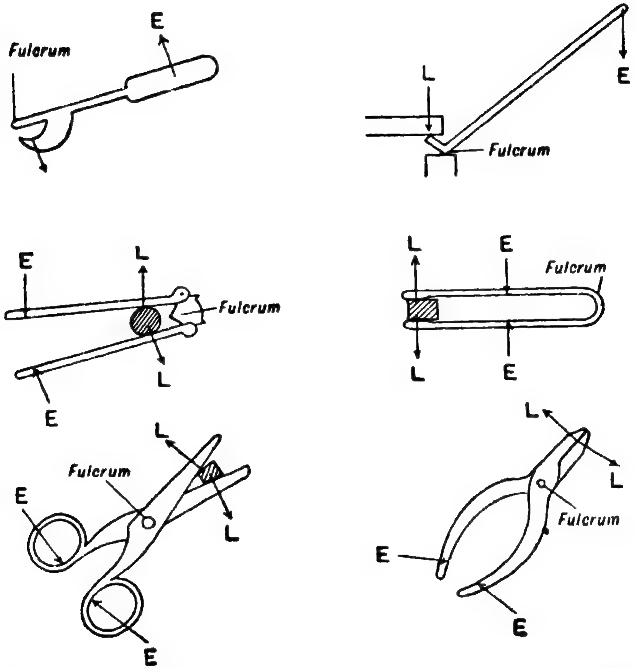


FIG. 20. HOUSEHOLD APPLIANCES WHICH ARE SIMPLE LEVERS.

of them, such as the scissors and the crowbar, the load and effort are on opposite sides of the fulcrum, while in others, the nutcrackers and the sugar tongs, they are on the same side; but always less effort is required when the distance of the effort from the fulcrum is much greater than the distance of the load. The principle of the lever can be used to calculate the force exerted

by such machines. If the handles of a pair of nut-crackers are 6 in. long, a force of 1 lb. on each handle will produce a force of 6 lb on each side of the nut, assuming the nut is placed 1 in. from the fulcrum.

The winch. A simple form of winch is the arrangement used for raising a bucket of water from a well (Fig. 21). It consists

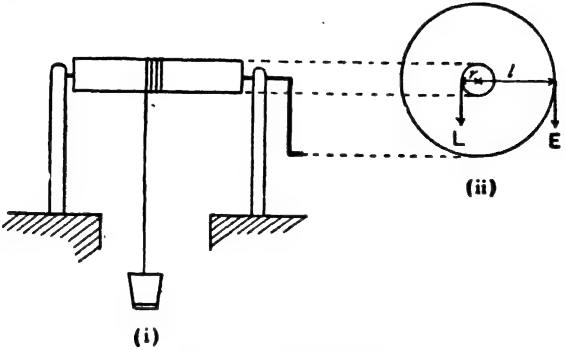


Fig. 21. The Winch.
(ii) shows how it acts as a continuous lever.

of a cylinder round which a rope is wound, a load being attached to the rope and a long handle fixed to the centre of the cylinder. The load is raised a vertical distance equal to the circumference of the cylinder when the handle makes one complete rotation. The winch is really a continuous lever, so that if a weight L is raised by an effort E, when l is the length of the handle, and r the radius of the cylinder, it follows from the principle of the lever that:

$$L \times r = E \times l.$$

$$\text{Mechanical advantage} = \frac{L}{E} = \frac{l}{r}.$$

The length of the handle l is always much greater than the radius of the cylinder r, so that the mechanical advantage is considerably greater than 1. The use of a handle on a variety of domestic appliances such as a mangle, a coffee grinder,

an ice-cream freezer, a mincer, depends on this principle; a long handle lessens the effort required to turn the centre axle of the machine, because the mechanical advantage is thereby increased.

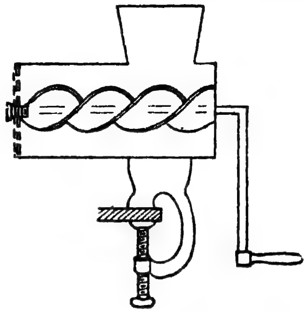


FIG. 22. A MINCER.

The long handle and the screw both help to increase the force exerted on the meat in order to press it through the cutter.

For example, if a mincer (Fig. 22) has a handle 8 in. long and the radius of the centre axle is $\frac{1}{2}$ in., the mechanical advantage is 16, and a force of 2 lb. on the handle produces one of 32 lb. at the entry of the mincer.

The pulley. A pulley is a wheel with a grooved rim in which a length of cord can move. The wheel can rotate about an axis through its centre, and this central axis is supported by a frame called the block. When the block is attached to a firm support, so that the axle is kept in a certain position, the pulley is a fixed one. From a consideration of mechanical advantage, there seems little practical value in a single fixed pulley; in fact the effort may be a little greater than the load because of friction but this effect will be discussed later. The value of a single fixed pulley does not then depend on its mechanical advantage; it is used because it is convenient for altering the direction in which a force is exerted. Generally it is far easier to pull downwards than to lift upwards, as, for example, when a clothes line has to be raised to the top of a post. Fig. 23 shows a rack for

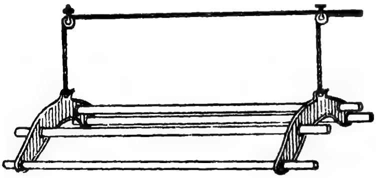


FIG. 23. RACK FOR DRYING CLOTHES INDOORS.

By means of pulleys screwed into the ceiling it can be raised to the top of a room.

drying clothes indoors ; by means of fixed pulleys it can easily be hoisted to the top of a room.

WORK

Work. The load overcome by a machine is not the only thing by which its effectiveness may be measured. When a force makes an object move, work is done, and the amount of such work depends, not only on the force but also on the distance through which it acts. For example, if a pile of books be lifted from the floor to a shelf 4 ft. from the ground, more work is done than if they be lifted to a shelf 2 ft. up. In this case, work is done by a person, and the force she uses must overcome the force pulling the books down, that is, their weight ; she exerts this force for 4 ft. or for 2 ft. and the work done in the two cases must be measured in terms of both force and distance.

Work = force × distance (the distance being measured in the same direction as the force is acting).

The British unit used is the foot-pound and 1 *ft.-lb. of work is done when a mass of* 1 *lb. is lifted a vertical distance of* 1 *ft.* In the example above, if the mass of the books were 6 lb., then $(6 \times 4) = 24$ ft.-lb. of work must be done to raise them to the top shelf, but only $(6 \times 2) = 12$ ft.-lb. to lift them to the lower one.

To measure the work done by the engine of a motor-car or by a large machine, the practical unit of horse-power is used, where

1 *horse-power* (*H.P.*) = 33,000 *ft.-lb. per minute.*

The time taken has therefore to be taken into consideration.

fiction = story tale

FRICTION – Rubbing

Friction. In most machines, much extra work must be done by the effort to overcome the friction of the various parts. However smooth a surface may appear to be, it really has minute irregularities, and when two surfaces come into contact,

these projections tend to become interlocked. This makes motion more difficult, for the effect is as if there is some *force opposing motion*; this is called **friction.**

Expt. 7. **Friction of various surfaces.** Fix a staple to one end of a smooth rectangular block and by means of a loop of string, attach a spring balance to the staple. Use a spirit-level to adjust various surfaces (a rough wooden board, a smooth wooden board, a sheet of glass, a piece of sandpaper) in a horizontal position. Hold the spring balance horizontally and draw the block across each surface in turn, giving it a slight push to start it moving (Fig. 24).

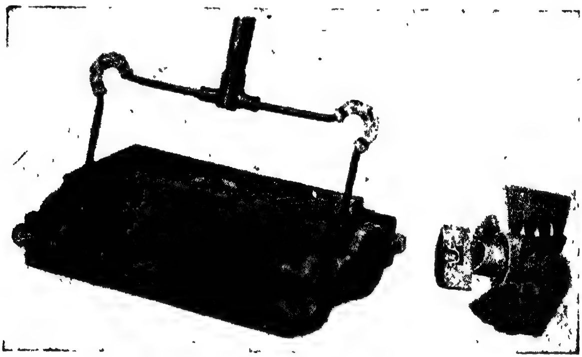
Fig. 24. Apparatus for comparing the Friction of various surfaces.

Note the reading of the spring balance when it is kept in uniform motion; if movement is jerky, repeat until a reading is obtained. Observe also the force required to start it from a stationary position. Find, for any one surface if the force required to keep the block moving varies when various weights are placed on top of the block.

In the experiment, the force due to the weight of the block acts vertically downwards, so that the only force opposing its motion horizontally must be friction. To keep the block moving, the pull exerted by the spring balance must just overcome this force of friction, and so the reading of the balance indicates the magnitude of the frictional force. As would be expected, the rougher the surface, the greater the friction. Also there is more friction before motion starts than when the object is kept moving; these two kinds of friction are called **limiting** and **sliding** friction. Additional weights on the block make friction increase; always increase of pressure between surfaces results in increased friction, and it seems as if the minute projections are pressed into more complete contact, so that it is more difficult to drag them apart.

Rolling friction. In constructing machines it is advisable to eliminate friction as far as possible, because the extra work

done by the effort to overcome it is merely wasted and is converted into heat. It is known that when a round body *rolls* on a surface, there is less friction than when it slides. For example, a cart has wheels which roll over the ground rather than fixed runners like a sledge, which slide ; a sledge is only used where rolling wheels would be impracticable. In any machine, much friction occurs where the axle of a wheel slides in a hub and to diminish this, ball-bearings are inserted ; small steel balls are



(i) (ii)

FIG. 25. A CARPET SWEEPER.

The ball bearings round the brush axle are shown in (ii).

(By courtesy of Entwhistle & Kenyon Ltd., Ewbank Works.)

placed between the axle and the hub, and these roll round as the axle turns. The wheels of roller skates, and the pedals and wheels of a bicycle contain ball bearings. Fig. 25 shows how they facilitate easy running in a carpet sweeper.

EFFICIENCY

Efficiency. The existence of friction makes it necessary to know something more about a machine than its mechanical advantage. Much of the work done by the effort may be used up in overcoming friction. For example, if a load of 100 lb. is

raised by an effort of 20 lb., but actually 10 lb. of this effort is used against friction, the actual mechanical advantage of $\frac{100}{20}=5$ might have been $\frac{100}{10}=10$, if there were no friction. For practical purposes, a machine is judged by its efficiency, which is defined thus:

$$\text{efficiency} = \frac{\text{work done } by \text{ machine}}{\text{work done } on \text{ machine}}$$

This value is expressed as a percentage. Since the work done *on* the machine represents all the work put into it by the effort, including that to overcome friction, the efficiency of any machine but a perfect one will be less than 100 per cent.; often it is only 50 per cent. Machines are oiled because oil between surfaces diminishes friction, and therefore increases efficiency.

ENERGY

Forms of energy. When an object can do work it is said to possess energy and the scientific definition of energy is *ability to do work*. Energy may exist in a variety of different forms and may change from one form to another as, for example, when the kinetic energy or energy of motion of a machine is used partly to cause further motion and partly by friction is transformed into heat. A case which shows a good variety of change is that of the motor-car; **chemical energy** is released by the explosion of petrol gas and air in the cylinder; some of this energy is transformed into **heat**, some into **kinetic energy** or energy of motion of the pistons in the cylinders; the latter energy is partly passed on to the car to give it motion, but some may be transformed into **electric energy** in the battery and thence to the **light energy** of the lamps. There is yet another form of energy, **potential energy** or energy of position; an object weighing 1 lb. placed 10 ft. above the earth could fall 10 ft. under the force of its weight and do 10 ft.-lb. of work; it possesses therefore the corresponding amount of energy. The

potential energy of the waters at the top of Niagara Falls is transformed into kinetic energy and finally to electric energy for supplying a vast area.

Nowadays there is a great deal of talk about **atomic energy**, which is a form of energy derived directly from changes in the structure of atoms. These changes result in the generation of *heat* which can be turned into *electrical energy*. This is how atomic power stations work. Fig. 25(A) shows the first atomic power station erected in Great Britain.

Although energy can be changed and sometimes seems to be wasted, as, for example, when friction turns it into heat, it can never be destroyed or created; as much appears in the new forms, as was originally present. The **conservation of energy** means that the total amount of energy remains unchanged.

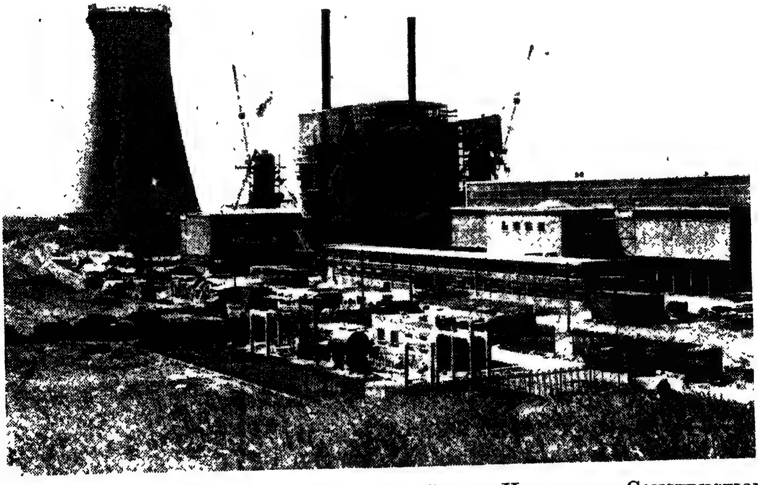


FIG. 25A. ATOMIC ENERGY POWER STATION AT CALDER HALL UNDER CONSTRUCTION. Building in centre (with two chimneys) contains one of the atomic "furnaces"
(By courtesy of the United Kingdom Atomic Energy Authority. Copyright.)

CHAPTER III

FORMS OF MATTER. DENSITY. PRINCIPLE OF ARCHIMEDES. FLOTATION. FLUID PRESSURE

MATTER

Forms of matter. We are surrounded with a number of substances which we can touch and see and smell and feel. All such material things are called **matter**, and just as energy can exist in a variety of forms and change from one form to another, so matter may exist in any of the three physical states, **solid**, **liquid** and **gas**, and by supplying or removing heat, it can be made to change its state. Water is familiar to us as ice, water and steam, but most other substances generally seem to be in one particular state. So, for example, iron is regarded as a solid, but if it is heated enough, it becomes a liquid and can be made to boil and change into vapour. In the intense heat of the sun, iron only exists in the form of vapour. Similarly, air, which is considered to be a gas, can be cooled to such a low temperature that it is turned into a liquid very similar in appearance to water, and by cooling it still further, it can be frozen solid. The planets of the solar system when first formed from the sun were gaseous, but they have since cooled, and the Earth is now solid.

Properties of matter. The three kinds of matter have various characteristics. They all occupy space, offer resistance to forces acting on them, are compressible to varying extents, and possess inertia and weight. A gas may not seem to have these characteristics so markedly as solids and liquids, but the resistance of air to force is the reason that " stream-line "

motor-cars are now being made ; their shape is such that the resistance of the air is thereby diminished. To show also that air possesses weight, a spherical glass bulb fitted with a tap (Fig. 26) can be connected to an air pump and the air pumped out of it ; it is then weighed almost empty of air. When the tap is turned on, a hissing noise is heard as the air enters and a second weighing shows that there is an increase of weight. In a room at a normal temperature, 1 litre (1000 c.c.) of air weighs about 1·23 gm.

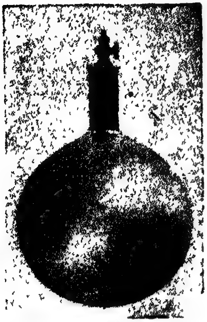


FIG. 26. GLASS BULB FOR WEIGHING AIR.

The solid state. A particular characteristic of solids is their **rigidity**, that is, their property of not altering readily their size or shape. If force is applied, so that they are twisted or pulled, they vary in their property of recovery, that is, in their **elasticity**. Metals such as gold, silver, copper and lead can be hammered into thin sheets and are **malleable** ; copper and silver can be drawn out into fine wires and are **ductile**.

EXPT. 8. **Elasticity of wires.** Take long fine wires of copper and steel of equal length and thickness. Attach them to a high beam in a room and fix scale pans to the ends of the wires, adjusting them so that both pans are equal distances from the floor. Add equal weights to the pans, and observe if the wires have stretched equally by noticing if the pans are still at equal distances from the floor. Remove the weights, and see if both wires recover their original length. Continue to add equal weights to both pans until the copper wire fails to recover. The copper has passed its *elastic limit* but the steel still recovers. Add heavier weights until both wires are permanently stretched and finally break ; the copper wire will probably not do so but will be drawn out into a still finer wire until the scale pan touches the floor.

Expt. 8 shows that steel wire is more *elastic* than copper ; it does not pass its **elastic limit** until subjected to much greater force than the copper wire. The copper wire, however, is more

ductile and is drawn out into a fine wire before breaking. Springs and clips are generally made of steel because of its great elasticity.

The liquid state. Liquids are not rigid like solids, but change their shape readily and flow until they occupy the vessel into which they are poured. Some liquids have more **mobility** than others and flow more easily ; some, like treacle, have a great **viscosity** and their particles seem to stick together so that neighbouring particles are only gradually drawn into the flow. The attraction between the particles of a substance gives the property of **cohesion.** It is present in solids, or the solid would crumble apart into powder ; it is shown in liquids by the tendency for drops to run together to form bigger drops ; in gases it is absent.

Certain other properties of liquids will be considered later in the chapter in connection with fluid pressure ; and such phenomena as surface tension, capillarity and osmosis will be discussed in Chapter XI.

The gaseous state. Gases as well as liquids, do not possess the property of rigidity, and both are described as *fluids*. Gases, however, possess much greater **fluidity** than liquids, because they expand and flow until they completely fill the vessel containing them, whereas a liquid takes the shape of the lower part of a vessel but shows a level surface. Gases also have great **compressibility,** and may be compressed to a small fraction of their original volume ; if free, however, they may expand almost indefinitely. The variation in volume of gases will be considered again in the next chapter in connection with the expansion due to heat.

DENSITY

Density. Individual solids, liquids and gases show certain differences. If a teacup is filled with granulated sugar and weighed, it will weigh more than if it were filled with flour. Or again, if it were filled with water and then with olive oil, the

weights would be different. Equal volumes of different kinds of solids, or equal volumes of different kinds of liquids do not weigh the same. It is said that the **density** of the substances is different. To compare this property in various substances, the mass or weight of a definite volume of each must be known; the volume chosen is 1 c.c. or 1 c. ft. according to whether metric or British measure is used. Thus the density of a substance is the mass of unit volume of it; the value may be expressed in grams per cubic centimetre or in pounds per cubic foot. For example, cane sugar has a density of 1·59 grams per cubic centimetre or 99·3 pounds per cubic foot.

For experimental purposes it is not necessary that exactly 1 c.c. of the substance should be available, because if the total volume of the substance is known, then the mass of 1. c.c. of it can be found by dividing the mass of the whole of it by the total volume (that is, total number of c.c.), so

$$\text{density} = \frac{\text{mass}}{\text{volume}}.$$

EXPT. 9. **Density of cheese.** Cut a cube of cheese exactly to the size of 1 c.c., weigh it and so find the weight of 1 c.c of cheese, that is, the density.

Now weigh the irregular lump of cheese remaining. Find its volume by dropping it into water in a graduated cylinder, and observing how many c.c. of water it displaces. Divide the weights by the volume and calculate the density. Compare this with the previous value.

EXPT. 10. **Density of water.** Weigh a dry, empty beaker. By means of a graduated cylinder, measure exactly 100 c.c. of water into the beaker. Re-weigh. From the difference of the two weighings, find the weight of 100 c.c. of water, and thence find the weight of 1 c.c. of water. The experiment may be repeated with other liquids.

Specific gravity or relative density. For commercial purposes it is convenient to have a method of comparing densities, which is independent of the weights and measures used in any

particular country. It has been shown experimentally that water has a density of 1 gm./c.c., so this is taken as a standard and other densities are compared with it. Thus cane-sugar with a density of 1·59 gm./c.c. has a density 1·59 times as great as water, and its relative density or specific gravity is 1·59. Specific gravity is merely a number denoting the number of times the density of a substance is greater than that of water; it is independent of units of volume, but care must be taken that both the density of the substance and of water are expressed in the *same* units, pounds or grams.

To find the specific gravity, the simplest method is to consider the weights of equal volumes of the substance and of water, for a comparison of these weights gives also a comparison of their densities. Thus:

$$\text{specific gravity} = \frac{\text{weight of a certain volume of a substance}}{\text{weight of an equal volume of water}}$$

It may be noticed that the specific gravity is *numerically* equal to the density expressed in gm. per c.c.

EXPT. 11. **Specific gravity of oil.** Obtain two kinds of oil and repeat Expt. 10 by finding the weights of equal volumes of water and oil. Calculate the specific gravity of each kind of oil.

If a substance like oil is being exported from one country to another, it may be quoted as having a certain specific gravity, the value of which is the same, whatever the units of weights in the two countries.

PRINCIPLE OF ARCHIMEDES

Principle of Archimedes. Everyone is familiar with the fact that objects appear to be lighter in water. When a girl is being taught to swim, it is quite easy to hold her up in a way that would be impossible on dry land. This is because the water itself is exerting some upward force and this buoyant effect

helps to support the person. The exact magnitude of this upward force was first stated by Archimedes. The **Principle of Archimedes** is that **when a body is suspended in a liquid its loss of weight is equal to the weight of liquid it displaces.**

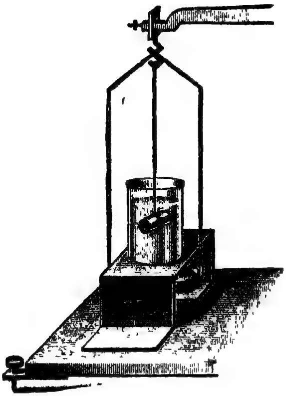


FIG. 27. METHOD OF WEIGHING A BLOCK SUSPENDED IN WATER.

EXPT. 12. **Principle of Archimedes.** Use cylinders or cubes of brass, copper, lead, etc. Measure one and calculate its volume. Suspend it by cotton from the arm of a balance and weigh it. Arrange a bridge over the pan of the balance and place a glass beaker of water on it, taking care that the block hangs freely and does not touch the sides of the beaker (Fig. 27). Be sure also that the bridge does not touch the pan of the balance. Weigh the block suspended in water. Repeat the experiment with the different blocks. Tabulate the results thus:

Material of block	Volume of block	Weight of an equal volume of water	Weight of block in air	Weight of block in water	Loss of weight in water
	c.c.	gm.	gm.	gm.	gm.

The weight of liquid displaced must be the weight of a volume of water equal in volume to the block. To test the truth of this principle, compare the third and last columns.

It seems as if the liquid displaced exerts an upthrust with a force equal to its own weight and so lessens the weight of the object suspended in it by that amount. The principle accounts for the apparent lightness of a person who is supported in water.

FLOTATION

Flotation. If an object is actually floating, the upward force of buoyancy is still more pronounced, for it is sufficient to keep the object suspended in the liquid. In both flotation and suspension, the upward force is equal to the weight of the displaced liquid. But in flotation, the upward force counterbalances the entire weight of the object, so that in this case, **the weight of the floating object is equal to the weight of liquid displaced.** This is often called the **Law of Flotation**; it is directly derived from the Principle of Archimedes.

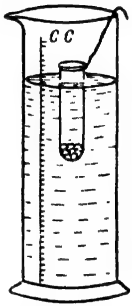


FIG. 28. EXPERIMENT TO ILLUSTRATE THE LAW OF FLOTATION.

EXPT. 13. **The law of flotation.** Pour water into a graduated cylinder until it is about half-full and read carefully the level of the water. Put a little lead shot into a test tube, tie a piece of cotton round the top and then by means of the cotton, lower the test tube into the cylinder (Fig. 28). If it does not float satisfactorily, vary the amount of lead shot. Read the level of the water in the cylinder, when the test tube is floating freely. Remove the test tube, dry it and find its total weight. Repeat the experiment with different amounts of lead shot in the tube. Tabulate results thus :

Weight of test tube and shot	First reading of cylinder	Second reading of cylinder	Difference of readings	Weight of water displaced
gm.	c.c.	c.c.	c.c.	gm.

Compare the first and last columns.

Depth of floating objects. All objects do not float ; and even those that do, float partly in and partly out of water to

varying extents. If the specific gravity is greater than 1, the whole of the object may be immersed and yet the weight of the displaced water remains less than the weight of the object, so that it sinks. A block of wood of specific gravity just 1, would float with its upper surface flush with the surface of the water, for the whole of it would have to be beneath the water to displace a weight of water equal to its own weight. Cork, with a specific gravity of 0·22, need only be approximately one-fifth submerged.

The specific gravity of iron is 7·2, and a block of solid iron would sink, but an **iron ship** has hollow compartments, so that

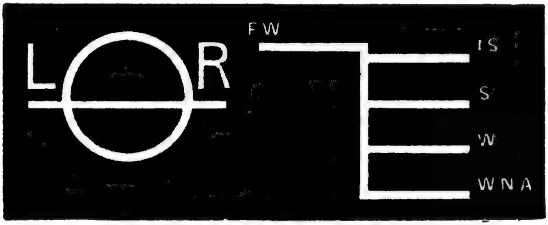


FIG. 29. THE PLIMSOLL LINE.

This is marked on the sides of all sea-going vessels and indicates the depth to which the vessel may be loaded. The letters L R refer to Lloyd's Register of Shipping, by whom the position of the line is assigned. FW, shows the line for fresh water; IS, Indian summer water; S, summer in temperate latitudes; W, winter in temperate latitudes; WNA, winter in North Atlantic.

the average specific gravity of the whole is less than 1. Even when partly immersed, sufficient water is displaced to equal the weight of the vessel, its engines, cargo and passengers.

The Plimsoll line (Fig. 29) is marked on the hull of all sea-going vessels to indicate the depth to which they can safely be loaded; if they are immersed too deeply they cannot withstand heavy seas.

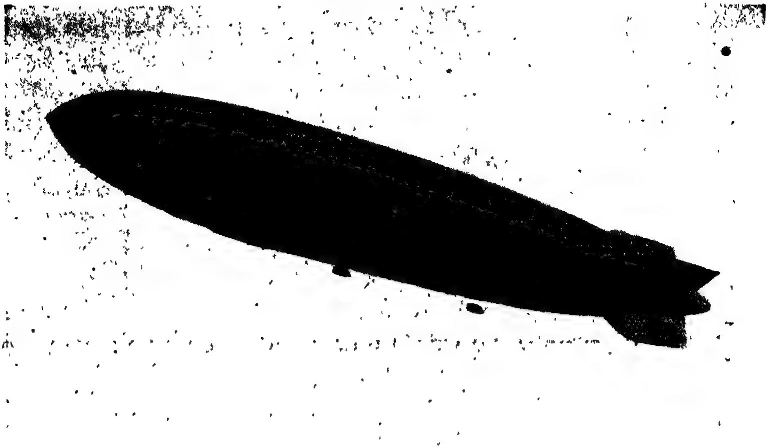


FIG. 30. THE "HINDENBURG" ON HER TRIAL FLIGHT.
(Copyright.)

The Law of Flotation applies to all fluids, gases as well as liquids. Thus an **airship** (Fig. 30) floats because the gas bags are filled with a gas like hydrogen or helium, which is very much lighter than air. It has been seen that air weighs about 1·23 gm. per litre while hydrogen only weighs 0·09 gm. per litre. Thus the total weight of the airship is less than that of the air it displaces, and it floats.

LIQUID PRESSURE

Pressure in liquids. When a girl floats in water, the buoyant effect she experiences is due to an *upward* force or pressure in the water. But if she stands up and walks through the water she will feel a pressure on her limbs, which makes movement difficult, and this pressure comes from every direction. Practical experience shows, therefore, that pressure in a liquid consists not only of the upward force which plays so important a part in flotation, but also of forces acting in all directions. This fact may be demonstrated by a syringe of the form shown in

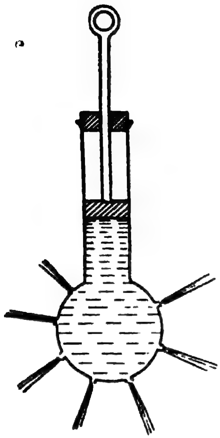


Fig. 31. A Syringe from which the Water is forced equally in all directions.

Fig. 31. The equality of the jets indicates that the pressure in all directions is equal.

If, however, a diver goes down into deep water, he finds that the deeper he goes, the greater the pressure on him, until at a depth of 150 ft., there is a pressure of nearly 70 lb. on every square inch of his body. Air is pumped into his dress to balance this water pressure, but even so he works under a considerable strain. A tall cylinder with three outlets (Fig. 32) can be used to show that pressure increases with depth; obviously the water from the bottom jet is being forced out at greater pressure.

Pressure in a liquid, then, is always the same at the same depth and is transmitted equally in all directions, but with increase of depth the pressure increases.

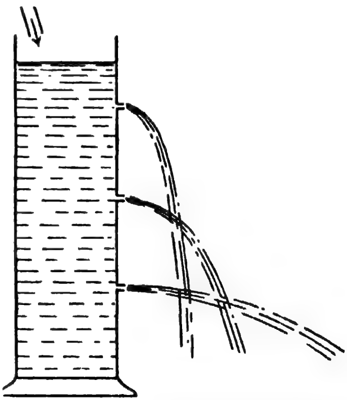


Fig. 32. The Pressure in Water increases with Depth.

Water level. If a bowl of water is tilted the surface of the water remains horizontal; it is as if the particles of water prevent the surface being inclined, because they slide down until it is horizontal again. This property is a characteristic of all liquids, and a popular way of describing it is by stating that *a liquid tends to find its own level.* To illustrate the phenomena, a number of vessels may be connected together (Fig. 33) and when water is poured into one of them it will flow until it is at the same level in all.

Town water supply. This tendency of water to find its own level is of the utmost value when it is necessary to take water through pipes from one place to another. Often a town gets its water from river or wells but large towns require big reservoirs; these are sometimes made by using lakes already existing and sometimes by damming up a valley in a mountainous region and making an artificial lake, preferably above sea-level. To supply Manchester with water, Thirlmere in the Lake District has had its outlet dammed, so that its level is raised 50 ft.; altogether the total height of its surface above Manchester is 580 ft. Pipes may go up hill and down dale, but providing they never go above the level of the surface of the water in the reservoir, the water will naturally flow along them.

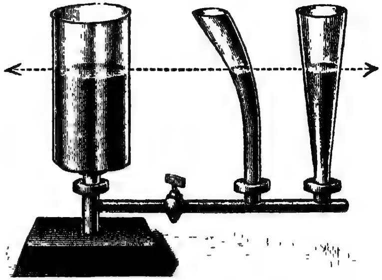


FIG. 33. THE WATER COMES TO THE SAME LEVEL IN ALL THE VESSELS.

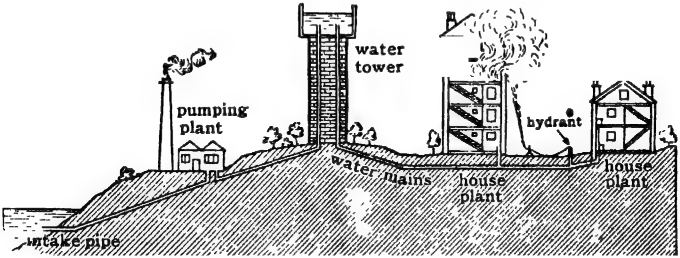


FIG. 34. TOWN WATER SUPPLY.

If the reservoir of a town is in a low position, a water tower is constructed (Fig. 34) and the water pumped up into it. The water having attained this level, it will flow naturally down the mains to the houses, and rise again to the upper floors of the houses. The higher the reservoir or the water-tower, the greater will be the pressure of the water supply, for it will be

that of a column of water of height equal to the vertical distance between a given tap and the surface of the water in the reservoir. If the top floor of a house were higher than the level of the water in the reservoir, no water could be obtained from a tap there, or if it were on fire, the water from the fireman's hose pipe would not rise high enough to be directed on the blaze.

GAS PRESSURE

Pressure of the air. When we walk out of doors in a wind we are conscious that air exerts pressure. Moreover, it has been seen that air has weight, and as it extends to several miles above the earth, it presses down with a pressure of 14·7 lb. on every square inch of surface, so that a person of average size is supporting a pressure of about two tons on the surface of his body. He does so unconsciously because the outward pressure due to the blood vessels and air cavities in the body is correspondingly great. On ascending to a great height, however, atmospheric pressure becomes much less and the excess of this outward pressure may cause discomfort and even sickness.

EXPT. 14. **Effects of the pressure of the air.** (*a*) Fill a tumbler with water and slide a piece of cardboard over the top, so that it presses tightly on the rim of the glass. Now invert the tumbler, holding the cardboard steady as you turn the tumbler over. The cardboard stays in place, and no water runs out, because the upward pressure of the air is greater than the downward pressure of the water.

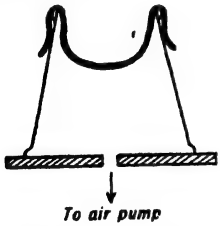


FIG. 35. DIAGRAM TO SHOW HOW RUBBER SHEETING BULGES DOWN WHEN AIR IS PUMPED FROM INSIDE THE CYLINDER.

(*b*) Place a cylinder open at both ends on the plate of an air pump; the rim in contact with the plate should be ground flat and greased so that it makes an air-tight contact with the plate. Over the top of the cylinder, tie a piece of rubber sheeting (Fig. 35). Pump the air from inside the cylinder. The rubber sheet bulges downward and finally bursts under the pressure of the air outside.

The barometer. A barometer is an instrument for measuring the pressure of the air. In its simplest form, a column of mercury balances the pressure of the air on the surface of the mercury in a vessel, and the height of the mercury column is a measure of atmospheric pressure.

A clean barometer tube (a thick-walled glass tube about a yard in length) is filled with mercury by pouring the liquid down a small funnel connected to the tube by a short piece of rubber tubing (Fig. 36 (i)). The tube is tapped to remove air bubbles, and to remove them all completely, a small air space is left at the top so that on placing the thumb over the end and inverting the tube several times, the air bubble from the space travels up and down, and collects smaller air bubbles on its way.

When the mercury is entirely free from air bubbles the tube is filled to the top, the thumb is placed over the end and the tube is inverted in a bowl of mercury, care being taken that the thumb is not removed until the end of the tube is below the surface of the mercury in the bowl (Fig. 36 (ii)). The tube is then clamped in a vertical position. The mercury falls from the top of the tube leaving a vacuum ; no air can possibly have entered.

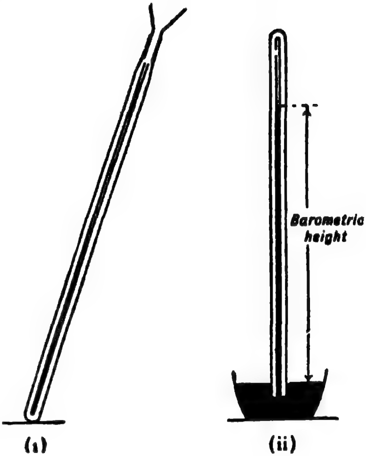


FIG. 36.
(i) How to fill a barometer tube.
(ii) The finished barometer.

The difference of level of the mercury in the bowl and in the tube measured vertically represents the atmosphere pressure for the day—about 30 in. or 76 cm. The pressure of the air varies from day to day and when it gets less the column of mercury falls, because less is required to balance the external

pressure ; when the pressure increases, the mercury rises higher in the tube.

The aneroid barometer. The kind of barometer in most general use is the aneroid one (Fig. 37). It has the advantage of being easily portable, especially since it can be obtained in a size no larger than a watch. It consists of a thin metal box rather like two tin lids soldered together at the edges, but with the top and bottom diaphragms of corrugated metal (the metal

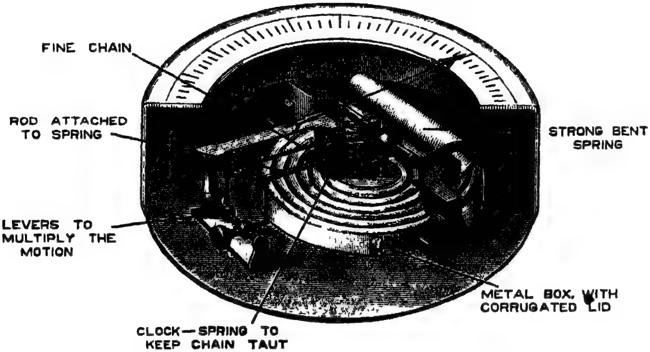


FIG. 37. THE ANEROID BAROMETER.

used is German silver). The box is exhausted of air, and but for the support of the spring on the upper diaphragm, the pressure of the air outside would make it collapse. The tension of the spring thus balances the pressure of the atmosphere, and when the latter alters there is a corresponding movement of the spring. By means of a system of levers, the movement of the spring is magnified and transferred to the pointer on the dial.

A further development of this type of barometer is the **barograph** (Fig. 38) in which a pen is fixed to the system of levers, and the movements of the pen are recorded by the line it traces out on a piece of paper, which is fixed to a drum revolving once a week by clockwork.

Weather. A barometer is often called a " weather glass " ; and though it cannot be entirely depended upon to forecast

weather, yet, when the barometer is low, bad weather is probable. Weather variations in the British Isles depend

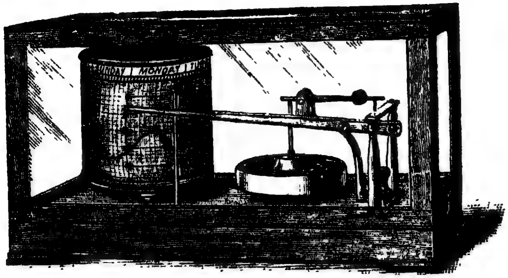


FIG. 38. THE BAROGRAPH.

chiefly on movements of air, coming generally from the Atlantic and travelling across the British Isles from S.W. to

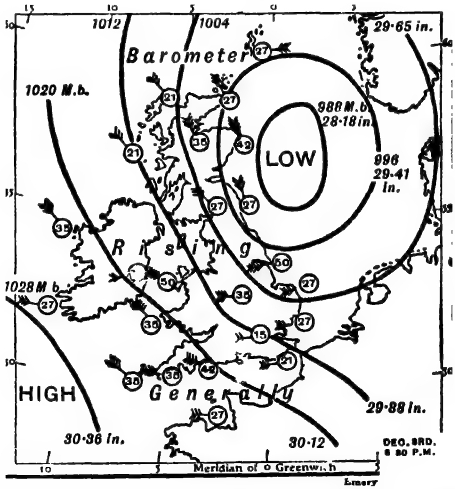


FIG. 39. WEATHER CHART SHOWING A CYCLONE OR LOW PRESSURE AREA.

N.E. Such movements are often regions of low pressure with the pressure increasing outwards (Fig. 39) and winds blow towards the centre of the region but are deviated because of the

rotation of the earth. Everyone is familiar with reports from broadcasting stations containing such remarks as "a depression is approaching from the Atlantic" and the conclusion drawn by the weather expert, "further outlook unsettled".

Charts are constructed at the Meteorological Office from barometer and wind records from certain stations on land and from ships at sea; on these charts all places of equal pressure are joined by lines called **isobars.** A region of low pressure indicates a **cyclone,** and one of high pressure with the pressure decreasing outwards indicates an **anticyclone.** Generally the former means bad weather and the latter, fine settled weather. From Fig. 39, the forecast would be that the weather was likely to improve since the cyclone was passing and an anticyclone approaching.

The common pump. The working of a common pump depends on air pressure. As the piston moves down by the action of the handle (Fig. 40) the piston valve opens under the pressure of the air beneath it, while the shaft valve remains closed. When the piston moves up again, the external pressure of the air keeps the piston-valve closed, but the pressure beneath it in the barrel is so small compared with the atmospheric pressure on the surface of the water in the well, that water rises up the shaft and passes through the shaft valve. When the barrel is full of water, the piston passes down through it with its valve open, but when it is raised, the valve closes and the water is lifted to flow through the spout.

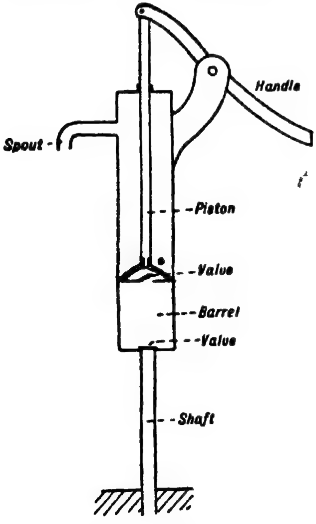


FIG. 40. THE COMMON PUMP.

The siphon. A siphon is a simple device for removing liquid from a vessel when pouring is impossible. To illustrate its

action a piece of bent glass tubing (Fig. 41) is filled with water ; one end is placed beneath the surface of the water in the vessel to be emptied, while the other end is kept closed till action is to begin. When this end is opened, water flows down the tube until the level in the top vessel reaches the end of the siphon.

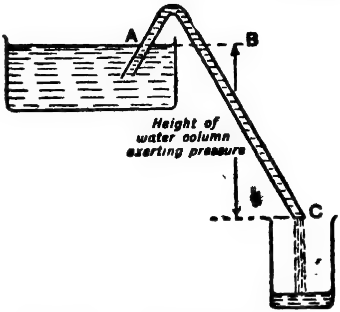


FIG. 41. THE ACTION OF A SYPHON.

At A, the surface of the water, the pressure is atmospheric. At a point B in the tube at the same level, pressure is the same as at A, that is, atmospheric, and the pressure is acting downwards. At C, there is an upward pressure equal to that of the atmosphere *minus* the downward pressure due to the column of water BC. So the pressure at B being greater than at C, water flows down until the surface level of the water is reduced as nearly as possible to that of the end of the pipe.

In a soda-water siphon the pressure of the carbon dioxide gas on the surface of the soda-water forces the liquid up the central tube and from this it can be released when the handle is pressed. The pressure decreases as the vessel empties and often the last amount of liquid cannot be forced out.

CHAPTER IV

HEAT AS ENERGY. EXPANSION. THERMOMETERS. QUANTITY OF HEAT. SPECIFIC HEAT. CHANGE OF STATE

Heat as energy. In Chapter II, heat was described as one of the forms of energy. The various kinds of energy cannot be seen or touched, but they can be studied, by the effect they produce on matter. For example, the electric energy in a lamp cannot be seen, but its effect on the filament is to make the wire glow brightly and so the white-hot wire can be observed but not the electricity itself. Similarly with heat, certain changes it produces on matter can be investigated although heat itself is invisible. Three changes familiar to us from practical experience are (1) change of size, (2) change of temperature, (3) a change of state.

EXPANSION

Expansion of solids, liquids and gases. Change of size, or expansion, occurs in all the three kinds of matter—solids, liquids and gases.

EXPT. 15. **Expansion of brass, water and air.** (*a*) Take a brass ball and ring of the type shown in Fig. 42. Pass the ball through the ring when cold; then heat the ball in a gas flame, and try again to pass it through the ring. Although no change in its size is apparent, it will remain stuck.

(*b*) Fit a flask with a long tube passing through the cork. Fill the flask with water and insert the cork carefully so that no air-bubbles collect beneath it; the water rises a little way up the tube. (Fig.

43 (i)). Place the flask in a vessel of hot water. Note that the level of the water is seen to fall very slightly (this is due to the expansion of the flask) and then to rise up the tube as the water gradually gets hot.

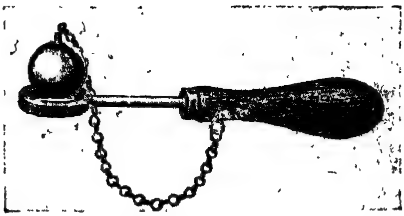


FIG. 42. EXPANSION OF A BRASS BALL.

(c) Use the same apparatus but support the dry *empty* flask in an inverted position with the end of the tube dipping beneath the surface of water in a beaker (Fig. 43 (ii)). Warm the flask gently with the hands or with a small gas flame. Notice the bubbles that rise through the water when the air inside the flask expands so that some is driven out of the tube. Let the flask cool; observe how water rises in the tube to take the place of the air that has been driven out. The amount of water entering is an indication of the volume the air has expanded relatively to the volume remaining in the flask; this expansion is very much greater than would be the case with a solid of similar size similarly treated.

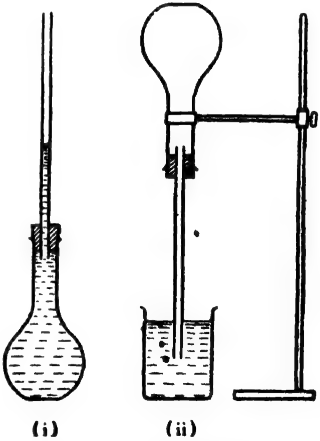


FIG. 43. EXPANSION OF (i) WATER, (ii) AIR.

Of the three kinds of matter, a gas expands by far the most, a liquid an appreciable amount, and a solid so little, that the change can barely be detected with the naked eye. An experiment with different gases would show that they all expand very nearly equally, whereas different kinds of liquids and solids expand differently.

Fire-proof materials. Certain materials now on the market are compounded so that their expansion is extremely small, and they are therefore strong to withstand changes of temperature. One such material, **vitreosil**, made chiefly of fused silica, expands only one-seventeenth of the amount that glass does. When made red-hot, it can be plunged into cold water without cracking. It is used for bowls and globes for gas and electric lights, there being no danger of its breaking when heated or cooled excessively. **Pyrex** and other forms of oven glass are specially made so that their expansion is extremely small, and dishes and bowls made of such material can be used both for cooking and serving food, thereby saving labour.

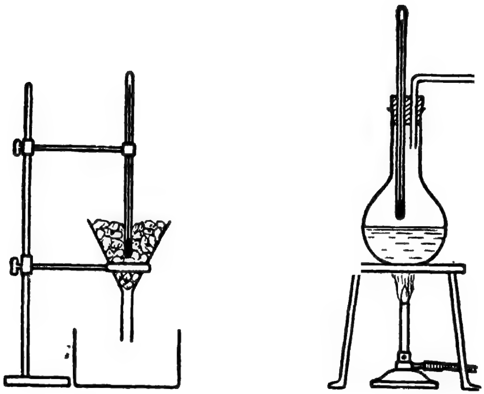
THERMOMETERS

Thermometers. Change of temperature is measured by means of thermometers, the majority of which work on a similar principle to the expansion of a liquid as seen in Experiment 15. Mercury or alcohol are used rather than water, because they can be used over a wider range of temperature without turning to solid or to vapour.

Fixed points. For measuring purposes, certain definite temperatures must be taken as standards. Since water is a very common substance, it is used for determining the fixed points of thermometer scales; the temperature of pure melting ice is taken as the **lower fixed point**, and the temperature of the steam from water boiling under normal atmospheric pressure as the **upper fixed point**. Two different types of thermometer are in general use, the **Fahrenheit** and the **Centigrade**. The Fahrenheit is commonly used in Great Britain; and on this scale the lower fixed point (the freezing point of water) is 32° F. and the upper fixed point (the boiling point of water) is 212° F. The Centigrade scale is used in all scientific work, and in most of the countries of Europe; the corresponding temperatures of its fixed points are 0° C. and 100° C.

Expt. 16. Verification of the fixed points of a thermometer. (*a*) Fill a funnel with small pieces of *clean* ice and fix both Centigrade and Fahrenheit thermometers in position for a few minutes as shown in Fig. 44 (i) ; test their lower fixed points in this way.

(*b*) Test the upper fixed points of the same thermometers by supporting them as shown in Fig. 44 (ii), so that as much as possible of the mercury thread is surrounded by the steam from vigorously boiling water and only a few graduations near the fixed point are above the cork.



(i) (ii)

Fig. 44. Verification of the fixed points of a Thermometer.

The values of 100° C. and 212° F. are only correct if atmosphere pressure is 76 cm. A book of tables must therefore be consulted to find the boiling point for the pressure on that particular day ; any error in the fixed points of the thermometers can then be estimated.

From the values for the fixed points, it is obvious that there are 180 degrees between the two fixed points on the Fahrenheit scale and only 100 on the Centigrade one. A Fahrenheit degree is therefore $\frac{100}{180}$ or $\frac{5}{9}$ of a Centigrade one.

The clinical thermometer. A clinical thermometer (Fig. 45) is one used for taking the temperature of the human body. It is a small mercury thermometer about four inches long, marked in Fahrenheit degrees from 95° F. to about 110° F. ; these are

the limits between which the temperature of the living human body varies. Each degree is divided into fifths, so that decimals of a degree can be read.

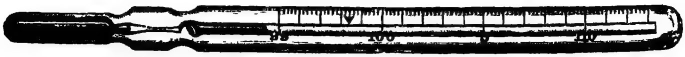


FIG. 45. THE CLINICAL THERMOMETER.

The unique point in the construction of this thermometer is a constriction in the bore of the stem just above the bulb, the purpose of which is to make the mercury thread stay in position after the thermometer is removed from the patient's mouth. When the thermometer is used, it is put under the tongue or in the armpit; the warmth makes the mercury expand and force its way through the constriction. It is then removed, and since the mercury breaks at the constriction and cannot flow back into the bulb, the reading remains the same as when the thermometer was in contact with the patient. To set it for further observation, it must be jerked sharply downwards to send the mercury back through the constriction.

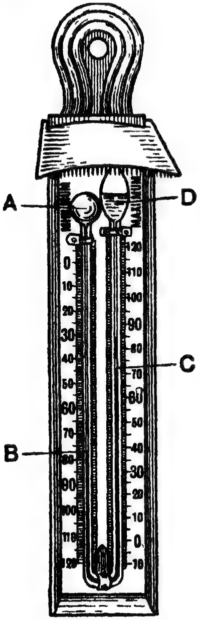


FIG. 46. A MAXIMUM AND MINIMUM THERMOMETER.

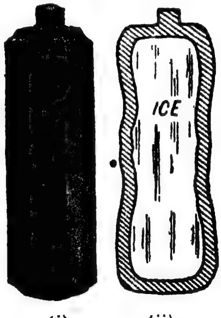
A person in good health should have a temperature between 97·8° F. and 98·6° F., the majority of people being generally slightly below the temperature marked normal, 98·4° F. A temperature of over 100° F. indicates definite fever, and although exceptional cases of very high temperature occur in tropical fevers, one of over 105° F. indicates dangerous illness.

Maximum and minimum thermometer. It would be inconvenient to watch a thermometer to see the highest and lowest temperatures of the air, during twenty-four hours, so in the maximum and minimum thermometer (Fig. 46) a record of the extreme

temperatures is obtained from two small steel floats. In bulb *A* there is alcohol; the alcohol extends down the stem to *B*. From *B* to *C*, there is a thread of mercury and from *C* to *D* alcohol again, while the bulb *D* contains alcohol and alcohol vapour and air. The thermometric expansion and contraction is produced by the alcohol in *A*, the mercury and the other alcohol merely being present to assist the working of the thermometer.

When the thermometer rises the alcohol in *A* expands and pushes the mercury thread round, and this in turn pushes the float in the right-hand side of the tube to the highest temperature occurring. When it becomes cooler, the alcohol contracts and the mercury follows it back, pushing the float in the left-hand side to the lowest temperature. The steel floats have tiny springs attached, which keep them in position, and a magnet has to be used to draw them down to the ends of the mercury thread to reset the thermometer.

Behaviour of water. Most substances expand steadily when heated and contract when cooled, but water behaves in a curious fashion. As it cools, it contracts till it is at a temperature of 4° C. and then it expands again from 4° C. down to 0° C. When it is most contracted, it must have its greatest density, so 4° C. is called the temperature of **maximum density of water.** At 0° C., water expands again on changing into ice.



(i) (ii)

Fig. 47.

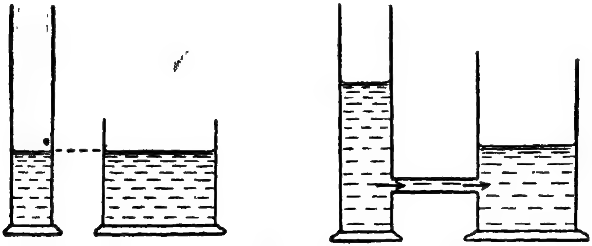
(i) A cast-iron bottle. (ii) The bottle burst by the expansion of water on freezing.

This latter effect can be shown by freezing a cast-iron bottle full of water. The bottle is fitted with a screw top which can be tightly fixed with a spanner, and it is covered with a freezing mixture of 3 parts of ice to 1 of salt. After five or ten minutes, a bang is heard, and the bottle is found broken asunder with a thick layer of ice inside (Fig. 47). The force of expansion is sufficient to burst the cast-iron bottle.

The behaviour of water affects certain everyday phenomena. The maximum density of water ensures that the water at the bottom of a pond (*i.e.* the most dense water) is at 4° C., when there is a thick layer of ice at the surface ; consequently fish can continue to live in the water. Further, ice is lighter than the water (since water expands on freezing), and so it can float on the top of a pond, and similarly ice-bergs can float in the sea. Water-pipes often burst in frosty weather, when the water inside them freezes. Generally this is not realised immediately, because the ice blocks up the gap in the broken pipe, but directly there is a thaw the ice melts and the water gushes out of the crack.

QUANTITY OF HEAT

Difference between temperature and quantity of heat. In the ordinary way, people talk of " heat " when they actually mean " temperature ". But *heat and temperature are not identical.* An analogy with water will make the difference clear.



(i) FIG. 48. (ii)

In (i) jars filled to the same level do not contain equal quantities of water. In (ii) water flows from one vessel to the other until the water in each is at the same level.

Temperature may be likened to level of water, and quantity of heat to quantity of water. Two vessels (Fig. 48 (i)) may contain water at the same level, but there is not the same quantity of water in each. So two bodies (as, for example, the brass and water in the experiment that follows) may be at the same tem-

perature, but not contain the same quantity of heat. Moreover, two vessels may contain water at different levels, and if the vessels are connected, water will flow from the one at a higher level to that at a low until both are at the same level (Fig. 48 (ii)). So if a body is at a higher temperature than others near it, heat will flow from it until the temperature is uniform everywhere. Temperature, then, may be defined as that *condition* of a body which determines whether it shall give heat to, or receive heat from, its surroundings.

EXPT. 17. **Difference between heat and temperature.** Into two similar glass beakers measure 200 c.c. of cold water by means of a graduated cylinder ; place a thermometer in each and note the temperature of the cold water. These two vessels are to receive heat from *equal weights* of brass and water heated to the *same temperature*. Place a 200 gm. brass weight and 200 gm. of water (obtained by

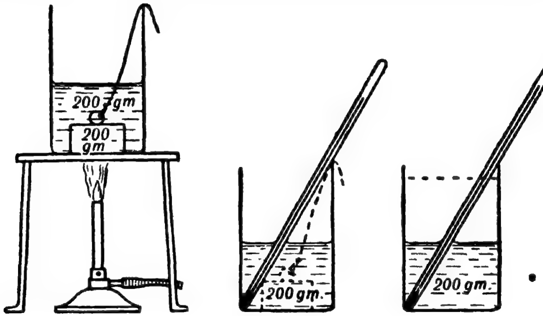


FIG. 49.

Equal quantities of brass and water at the same temperature do not contain equal quantities of heat.

measuring out 200 c.c.) in a third beaker, first attaching a piece of cotton to the weight, so that it can easily be lifted out (Fig. 49). Heat this beaker over a bunsen flame, and immediately the water boils, transfer the weight quickly to one beaker of cold water and the hot water to the other ; stir and note the resulting temperature.

The beaker receiving the hot water is found to be at a much higher temperature, thereby showing that, although the brass and hot water were at the same temperature, the hot water contained more heat.

Measurement of heat. Quantity of heat is an amount of energy measured in terms of its power of raising the temperature of water. The metric unit of heat is the **calorie**; the *quantity of heat required to raise the temperature of* 1 *gm. of water through* 1° *C.*, or given out by 1 gm. of water in cooling through 1° C. For general purposes in this country, the unit is the **British Thermal Unit**; *the quantity of heat required to raise the temperature of* 1 *lb. of water through* 1° *F.*, or given out by 1 lb. of water in cooling through 1° F. The latter unit is the larger; 1 B.Th.U. corresponds to 252 calories. From these definitions it can easily be calculated what quantity of heat is required to warm water; for example, a gallon of water (that is, 10 lb.) when heated through 150° F. absorbs 1500 B.Th.U.; and a litre of water (1000 gm.) heated through 50° C. absorbs 50,000 calories.

Incidentally, water has a higher capacity for heat than any other substance, so a similar quantity of oil or an equal weight of brass would need very much less heat to raise its temperature to the same extent. The **heat capacity** of a substance is the quantity of heat required to raise unit weight of that substance through one degree. The ratio of the heat capacity of a substance to the heat capacity of water is termed the **specific heat** of that substance. But since from the definition of calorie and British thermal unit, the heat capacity of *water* is always 1, heat capacity and specific heat are numerically equal. The relation between the terms is similar to that between density and specific gravity, except that these latter are only numerically equal when metric measurements are used.

Experiment 17 might also have been used to find the specific heat of brass, and a similar but more accurate experiment may be done to find the value for copper.

Expt. 18. **Specific heat of copper.** Weigh a copper can (known as a calorimeter) first empty, and then two-thirds full of cold water. Take the temperature of the cold water. The calorimeter may be placed in a larger can on a cork with a few light pads of

cotton wool round to prevent gain or loss of heat from the surroundings. Now place about 30 gm. of copper shavings in a test tube and support it in a flask half-full of water, so that when the water boils, the test tube is surrounded by steam. Let the water boil some minutes; take the temperature of the copper and if it is steady, quickly transfer the copper shavings to the cold water in the calorimeter. Stir and read the temperature of the mixture. Weigh again to find the weight of copper added.

From the definitions, the specific heat is numerically equal to the heat capacity, *i.e.* the heat given out by a gm. of copper cooling through 1° C. Obtain an expression for the total heat lost by the copper (with the specific heat as x) and form an equation thus:

Heat lost by copper shavings = heat gained by cold water,

$$i.e. \quad \left.\begin{array}{c}\text{weight of water}\\ \times\,\text{rise in temperature}\end{array}\right\} = \left\{\begin{array}{c}\text{weight of copper} \times \text{fall in}\\ \text{temperature} \times \text{specific heat } (x).\end{array}\right.$$

This assumes that all the heat given out by the copper is absorbed by the water, but actually the calorimeter absorbs a little. However, a fairly accurate value for the specific heat should be obtained.

Effect of specific heat on climate. Water, with its value of 1, has a higher specific heat than any other liquid or solid. Thus a large quantity of water, such as the sea, takes much longer to be heated up by the sun than the land and similarly cools much more slowly. Islands or places on a sea-coast tend to have a much more equable climate with less extremes of heat and cold than inland places. The differences between winter and summer temperature in England are only half as great as the corresponding differences in parts of central Russia in the same latitude.

CHANGE OF STATE

Change of state. In describing the three forms of matter in Chapter III, it was said that changes from one state to another could easily be achieved by heating or cooling the substance, and that the actual state of a substance at any particular time depended on its temperature. The simplest substance in which to study these various conditions is water.

EXPT. 19. **Heat required to change ice to water and water to steam.** Crush some ice into small pieces and place a handful in a metal can. Observe the temperature with a Centigrade thermometer. Stand the can on a tripod stand, and at the beginning of a minute as noted on a stop-watch, place a *small* flame beneath the can. Stir thoroughly and note the temperature of the ice as it melts; it should remain at 0° C. At the instant that all the ice has melted, note the time again. Then observe the temperature every minute and note the time when the water begins to boil. Let the water continue to boil until it has all boiled away and note the time when the last drop disappears; this last interval will be much longer than the previous one.

Assuming that the burner has been supplying heat steadily, the relative times for the changes—ice to water, water at 0° to water at 100°, water to steam—are proportional to the amounts of heat associated with each change. Suppose it takes 4 minutes for ice to turn to water, 5 minutes for water at 0° C. to be raised to 100° C. and 25 minutes for all the water to boil away, it is known that 1 gm. of water heated from 0° C. to 100° C. required 100 calories of heat; then 1 gm. of ice to melt required $(100 \times \frac{4}{5}) = 80$ calories and 1 gm. of water changed to steam requires $(100 \times \frac{25}{5}) = 500$ calories.

Melting point. The exact temperature at which a solid changes to liquid is called the melting point of that substance. The values for different substances vary tremendously as, for example, 0° C. for ice and 1530° C. for iron. So long as any of the solid remains unmelted the temperature remains unchanged; this was shown with ice and water, and in practical experience it is known that the fat in a frying pan does not get very hot until all has become liquid.

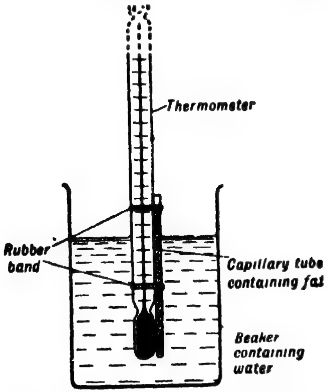


FIG. 50. HOW TO FIND THE MELTING POINT OF A FAT.

EXPT. 20. **Melting point of butter.** Dip a short piece of thin glass tubing into some melted butter, so that the tube is filled; it quickly solidifies. Now attach the tube with rubber bands to the bulb of a thermometer (Fig. 50) and

place it in a beaker of water. Heat gently, stir, and read the temperature directly the butter is seen to melt. Remove the flame; let the water cool and read the temperature as the substance solidifies. Repeat, and take the mean of the observed temperatures as the melting point. The melting point of butter and margarine may be compared and used as a method of detecting mixtures of the two.

Variation of melting point. When substances are mixed together their melting point is altered. For example, bismuth, tin, lead and cadmium all have melting points above 200° C.,

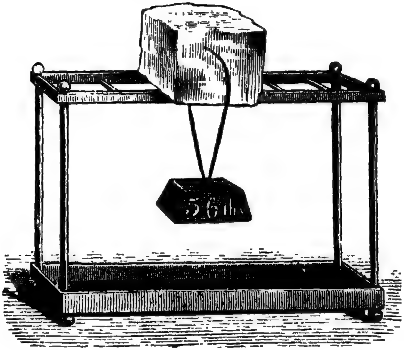


FIG. 51. REGELATION.
The wire passes through the block of ice, yet the block remains intact.

but when the metals form an alloy known as Rose's fusible metal, the alloy melts at 70° C. Salt lowers the melting point of ice as may readily be seen by taking the temperature of a mixture of the two.

Melting point is also affected by pressure. If a copper wire is fastened to a heavy weight and hung over a block of ice (Fig. 51) the wire will pass through the ice without apparently cutting it. Pressure lowers the melting point of ice, so that beneath the wire it is melted and the wire passes through; the water so formed is then free from pressure, and being surrounded by ice, refreezes.

This phenomenon is known as **regelation**. It occurs when snow is pressed together to form a snowball, or when two pieces of ice are stuck together. Glaciers take the shape of the valleys and curve round rocks, because pressure makes the ice melt, and the water takes the required shape ; if the pressure is removed, regelation (or re-freezing) occurs (Fig. 52).

Difference between evaporation and boiling. A liquid can change to vapour by two processes—evaporation and boiling. Evaporation takes place at any temperature, and only occurs

Photo. *W. N Spooner & Co.*

FIG. 52. THE CURVING PATH OF A GLACIER AS IT FLOWS DOWN THE MOUNTAIN SIDE.

at the surface of the liquid ; its cooling effect has already been discussed. Boiling takes place at a definite temperature for one particular liquid, providing the atmospheric pressure does not vary, but it is different for different liquids and serves as a means of identifying them. In boiling, bubbles of vapour are formed throughout the liquid, and the " singing " noise heard just before a kettle of water boils is due to the rattling noise made by the bubbles collapsing before they reach the surface. When the water boils, the bubbles burst at the surface.

Boiling point. In determining the boiling point of a pure liquid, the bulb of the thermometer is placed in the vapour above the liquid because the vapour is free from any impurities present in the liquid. The boiling point of a solution is determined by placing the thermometer in the liquid itself.

EXPT. 21. **Boiling point of water to which salt has been added.** Use the flask fitted up in Experiment 16 (*b*). Half fill it with water and add a teaspoonful of salt to the water. Adjust the thermometer in the cork so that it will be above the liquid and be only immersed in steam. Heat the flask and note the temperature when the solution is boiling. Now arrange the thermometer so that the bulb is in the solution. Again read the temperature when the solution is boiling. Add more salt and repeat.

By placing the thermometer in the steam, the boiling point of pure water was observed; that of a solution is higher. When fruit or vegetables are boiling in water some of their constituents dissolve in the water to form a solution and the boiling point is therefore higher than 100° C.

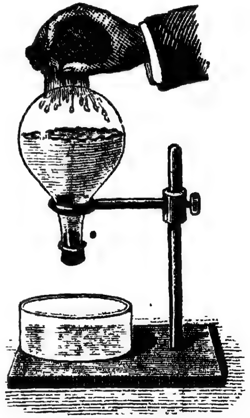


FIG. 53. WATER BOILS AT A LOWER TEMPERATURE WHEN THE PRESSURE ON IT IS REDUCED.

Variation of boiling point with pressure. The boiling point of a liquid varies with the pressure of the atmosphere in contact with it.

This may be shown by heating a round-bottomed flask half-full of water, and corking it tightly when the water is boiling freely. On inverting the flask, so that it can conveniently be cooled (Fig. 53) the water is seen to boil again. Even when cooled considerably, the water continues to boil. The effect is due to the lowering of the pressure on the surface of the water. All the air is

driven out of the flask by the steam, so that when the flask is corked, the space above the water contains only steam. When the flask is cooled, the steam condenses and since 1600 c.c. of steam in condensing only form 1 c.c. of water, the volume of water formed is insignificant compared with that of the steam. The pressure inside the flask is then lowered and the water boils at temperatures considerably lower than 100° C.

The boiling point of water is only exactly 100° C. or 212° F. when the barometer reading is 76 cm.; it becomes lower when the pressure is less or higher when it is greater; for example, water boils at 99·6° C. when the pressure is 75 cm., and 100·4° C. when it is 77 cm. Since pressure decreases on going up a mountain, it is impossible to make good tea or cook food properly at the top of a high mountain because the boiling point of water is so low; at the top of Mont Blanc it is 85° C., and on the Mount Everest expeditions, much lower boiling points must have been experienced. Use is made of increased boiling point in steamers for cooking food very rapidly; the vessels are made so that the steam only escapes under pressure, and the liquid inside boils at a higher temperature than normally.

Latent heat. The change from solid to liquid, or vice versa, is termed the **lower change of state** and that from liquid to gas the **upper change of state.** In both cases a quantity of heat is involved in the change, and since this heat seems "hidden" or stored up in the substance when it changes from a lower to a higher state and is given out when it returns to the lower one, it is called **latent heat.** The **latent heat of fusion** of ice is the *quantity of heat required to change* 1 *gm. of ice at* 0° *C. to water at* 0° *C.* Similarly the **latent heat of vaporisation** of water is the *quantity of heat required to change* 1 *gm. of water at* 100° *C. to steam at* 100° *C.* The values given in the experiment are approximately correct. The latent heat of fusion of ice is 80

calories and the latent heat of vaporisation of water is 540 calories. Snow remains on the ground so long after a thaw, because almost as much heat is required to melt each gram of it (80 calories) as to warm a gram of water to boiling point (100 calories).

Cooling effects due to latent heat. Practical use can be made of the cooling effect produced by substances absorbing their latent heat from their surroundings in order to melt. Cold drinks are prepared by putting lumps of ice in them ; every gram of ice absorbs 80 calories of heat from the surrounding liquid in melting in addition to another (say) 10 calories in being warmed up to the rest of the mixture. To make ice for such purposes and to keep food cool, refrigerators are used and their construction depends on the cooling effect of evaporation, that is, the latent heat absorbed by a liquid from its surroundings in turning to vapour.

EXPT. 22. **Cooling effect of evaporation.** Make a small pool of water on a block of wood, and stand a glass beaker in it (Fig. 54). Pour some ether into the beaker and blow air through it by means of glass tubing connected to air bellows by rubber tubing. Ether is used because it evaporates quickly and has a pronounced effect. After frost has been seen to form on the outside of the beaker, try to lift the vessel. It will be found to be frozen to the block, and the block can be lifted attached to the beaker. On breaking them apart, a thin layer of ice will be found between the two. Feel how cold the ether is.

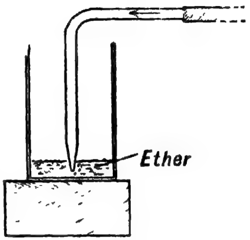


FIG. 54.
Water is made to freeze by the cooling effect of ether evaporating.

The various types of household **refrigerators** all work on this principle of the cooling caused by a liquid evaporating and absorbing heat from its surroundings. The liquids in common use as refrigerants are ammonia, sulphur dioxide, carbonic acid and ethyl chloride. In one type of refrigerator

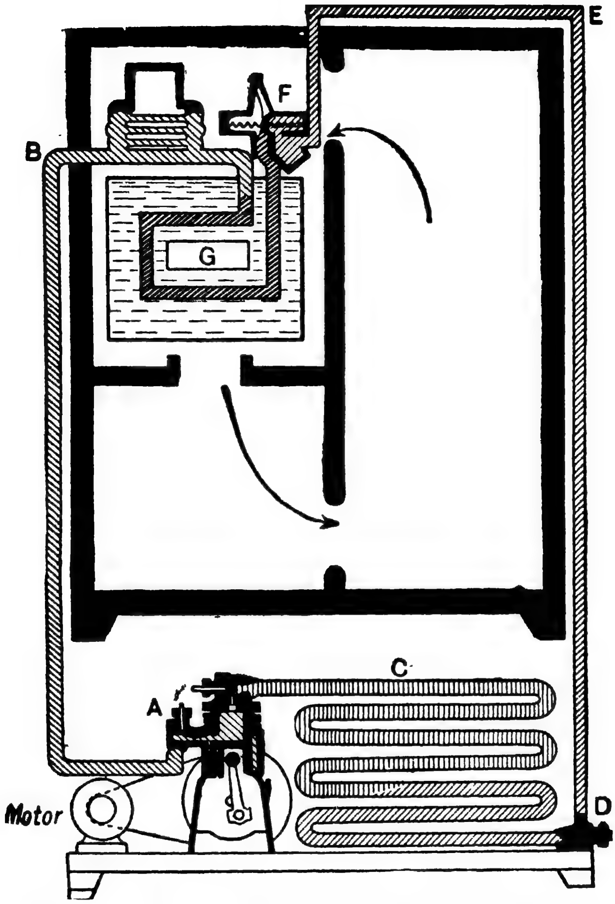


FIG. 55. HOW A HOUSEHOLD REFRIGERATOR WORKS.
(By courtesy of Kelvinator Ltd.)

(Fig. 55) in which liquid sulphur dioxide is used, a compressor *A*, draws sulphur dioxide gas down the tube *BA*, so that the gas is compressed in the coils of the condenser *C*, and converted into liquid. It passes as a liquid up the tube *DE*,

and is allowed to expand through a regulated expansion valve *F*. Here the pressure is much less, and the liquid turns to vapour in the coils of the cooling unit *G*; as it does so, it absorbs heat from the brine in the surrounding tank. This brine becomes very cold and takes heat from the surrounding metal cooling unit, so that the latter is generally covered with frost.

Trays of water can be placed by the cooling unit so that cubes of ice are produced for table use. The air inside the refrigerator circulates as shown by the arrows, so that food on the shelves is kept from deterioration by being maintained at a temperature between 40° F. and 50° F. The compressor is worked by a small electric motor connected to the mains, but since this uses very little electricity, the cost of running the refrigerator is extremely small.

CHAPTER V

TRANSFERENCE OF HEAT. VENTILATION AND HEATING OF BUILDINGS

How the sun's heat reaches the earth. The real source of all heat on the earth is the sun, because the various forms of fuel—coal, wood, gas, and so on—are substances depending originally on vegetable life, which must have sunlight for its growth. The sun radiates light and heat in all directions into space; an invisible substance called ether is supposed by scientists to fill all space, and the light and heat are transmitted by waves in the ether in a precisely similar way to wireless waves. The various forms of ether waves—heat, light, wireless, X-rays, ultra-violet light—all travel with the tremendous speed of 186,000 miles per second just as light does; hence it takes eight minutes for light and heat to reach the earth from the sun. The heat travels by **radiation**, one important characteristic of which is that it does not heat the medium through which it passes. Thus, outer space is extremely cold, and a few miles up in the air, there is a considerable lowering of temperature, the general rate of decrease being 3° F. for every 1000 ft. of ascent. This rate of decrease continues up to an altitude of 7-10 miles, but above this point the temperature is practically constant.

The air, then, is not warmed by radiant heat from the sun, but when the waves fall on the earth, some are absorbed and make the earth warm. The warm earth then gives up some of its heat to the air in contact with it, and the air gets warm by **convection**, that is, there is an upward movement of warm air and a downward movement of cold air towards the source of

heat. Some of the heat received by the earth is transmitted through the surface by **conduction**, the process by which solids become warm. Briefly, heat from the sun reaches the earth by radiation, and is further distributed by radiation, convection and conduction. Any source of heat loses its heat to its colder surroundings by these three methods.

RADIATION

Radiation. Any body that is at a temperature higher than its surroundings radiates heat in all directions. This radiant heat has certain characteristics. It seems to travel in straight lines, a fact we recognise, when we try to get into the shade

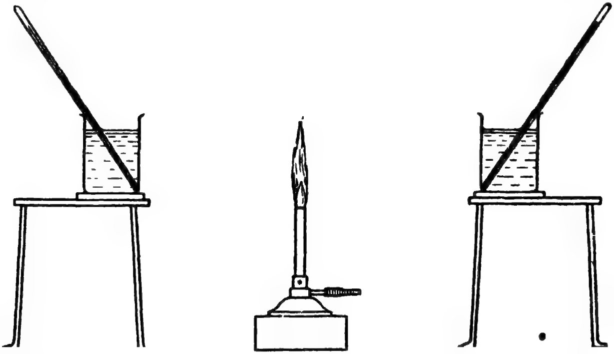


FIG 56. THE ABSORPTION OF RADIANT HEAT BY BLACK AND BRIGHT SURFACES.

away from the sun's rays, or when we place a screen in front of a fire. It has also been remarked that the radiation of the sun does not warm the air through which it passes, and similarly radiation from a fire does not warm the air of a room directly. When radiant heat falls on an object, some is reflected, some absorbed, and a little may be transmitted. All these three effects may occur in different proportion according to the nature of the surface and the object, but if one effect is very pronounced, the other two will be small.

EXPT. 23. **Absorption of radiant heat by a black and a bright surface.** Take two small metal cans of similar size; polish one brightly, and cover the other with soot by holding it in a candle flame. Pour exactly the same quantity of water in each, so that they are nearly filled and place them on stands about a foot apart, the height of the stands being such that the cans will be on a level with the flame of a bunsen burner (Fig. 56). If the stands are of metal, place cork mats under the cans to prevent loss of heat by conduction. Put a bat's wing top on the bunsen burner, and place it so that it is exactly equidistant from the two cans, with the broad side of the flame towards them; this is the source of radiant heat. At intervals of three minutes stir the water and record the temperature. Tabulate the results thus:

Time	Temperature of water in black can	Temperature of water in bright can
Minutes	°C.	°C.
0		
3		
6		
9		

Continue the experiment till there is 10° C. difference of temperature in the two columns.

Plot a graph showing the relation between time and temperature for the two surfaces.

Radiation and absorption. This experiment shows that a black surface absorbs radiant heat more readily than a bright one. This is because a dull, rough surface does not reflect heat very much, just as it does not reflect light, and so a relatively large proportion of the waves falling on it are absorbed. A bright surface, on the other hand, reflects more and absorbs less. Thus white clothes are cooler to wear in hot weather than black, and a white building is likely to keep cooler than a dark one.

A good absorber is a good radiator, so the dull black surface that absorbs heat well, also radiates it well, and a bright surface

is a poor radiator. A brightly polished metal tea-pot does not cool so rapidly as a dull one, because it does not radiate heat so well.

CONVECTION

Convection. Convection is a process in which particles move so that all in their turn receive heat from some body hotter than themselves. It takes place chiefly in liquids and gases, because the particles of such fluids are mobile. If some crystals of potassium permanganate are dropped in a flask of water that is being gently heated, streaks of colour show that the water is moving up the middle of the flask and down the sides (Fig. 57). This occurs because the water near the source of heat gets warm, expands, becomes lighter and rises, while the colder and heavier water sinks at the sides, and moves towards the source of heat. These streams of moving particles are called convection currents; eventually the whole of the liquid becomes warm in this manner.

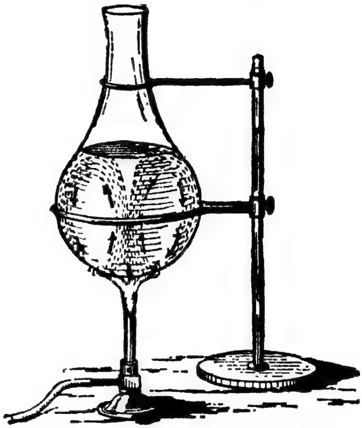


FIG. 57. MOVEMENT OF WATER WHEN HEATED.

Circulation of water by convection. This movement will take place even when the water is in tubes and not in a single vessel. Fig. 58 shows an arrangement which illustrates the circulation of hot water in a central heating or hot-water system. The water in the lamp glass at the top is coloured to show how movement is taking place. When the flask is heated, coloured water is seen to flow down the bent tube into the flask, while a layer of colourless water collects on the surface of the water in the lamp glass; this is due to warm water from the

flask rising up the straight tube and settling above the colder coloured water.

In the hot-water heating system of a house (Fig. 59) a boiler corresponds to the flask, and a cold-water cistern in the roof to the lamp glass. If the system is for heating only, there is only

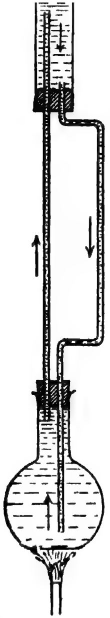


Fig. 58. Circulation of Water by Convection.

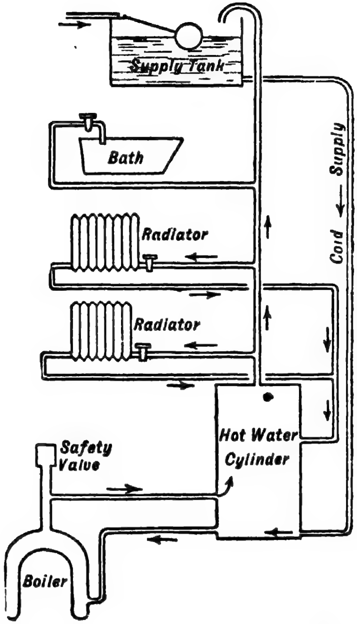


Fig. 59. Hot Water Heating System of a House.

a boiler from which the hot water flows, but where the hot water is to be drawn off by taps it is necessary to have a hot cylinder storage tank connected to the boiler ; this ensures a large supply of hot water when required. When water is drawn off by the taps, cold water from the cistern in the roof enters the cylinder by a pipe at the bottom. Often the cylinder is built into an airing cupboard, and in this cupboard warm air circulates by

convection, particularly if a space of one inch is left between the shelves and the wall.

Circulation of air by convection. Circulation of air by convection can be demonstrated with the apparatus of Fig. 60. Smouldering blotting paper is held over the lamp glass not above the candle, and the smoke mixes with the air and shows its direction of flow.

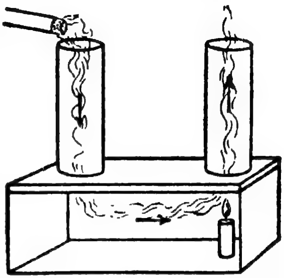
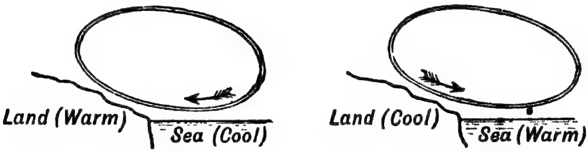


Fig. 60. Movement of Air when Heated.

Convection in the air occurs as a result of the heating of the earth by the sun, and the winds are due to these air movements. An example on a small scale are the land and sea breezes that occur in hot weather by the sea. It has already been seen that water has a higher specific heat than land ; it is, in addition, a poorer absorber of heat. Hence in the day, the land gets much warmer than the sea ; the air above it gets warm and rises, so that there is a sea breeze (Fig. 61). After sunset, land and sea



(i) Sea Breeze. (ii) Land Breeze.

Fig. 61.

radiate heat, but the land, having a lower specific heat and being a better radiator cools more quickly. The sea is then warmer and the convectional movement of the air causes a land breeze.

More examples of convection of air will be considered in connection with ventilation.

CONDUCTION

Conduction. Conduction is the process by which solids become heated ; the majority of fluids are bad conductors of heat. In conduction, the particles of the substance do not move, but heat is transferred from one particle to the next with which it is in contact ; this process continues through the substance, so that parts not themselves touching the source of heat yet receive heat from it.

EXPT. 24. **Different materials conduct heat differently.** Coat the rods of Ingenhousz's apparatus (Fig. 62) with a thin layer of paraffin wax, and fix them in the corks in the tank. The rods are of copper, aluminium, iron, lead, glass and wood. Now pour hot water into the tank and observe how the wax melts on the rods. It is left at a certain place on each rod and gives an indication of the conductivity of the different materials.

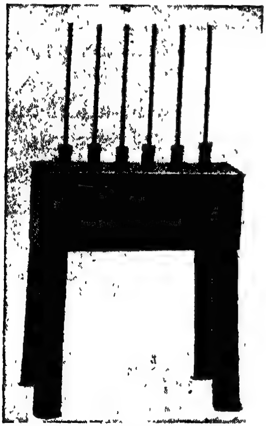


FIG. 62. INGENHOUSZ'S APPARATUS FOR COMPARING THE CONDUCTIVITY OF RODS OF DIFFERENT MATERIALS.

Copper is found to be a better conductor than aluminium. Actually silver is better even than copper, while lead and various alloys are the worst among the metals. Nevertheless all metals are good conductors and they therefore feel cold to the touch, because they conduct heat away from the hand. Most liquids are very bad conductors. Gases are worse conductors even than liquids, and the warmth of an eiderdown, or blankets, or a loosely woven woollen material is largely due to the non-conducting properties of the air interspersed in them.

Warmth of dwelling places. The warmth of a dwelling place largely depends on conduction through the walls. Tents used for camping in hot regions are made with double walls of canvas,

so that the air space between keeps the tent cool. Most houses in Switzerland have double windows and doors to prevent undue loss of heat from the interior of the house during very cold weather. The walls of a house should be as non-conducting as possible, if the house is to be warm in winter and cool in summer. The conductivity of the walls depends on such factors as the dryness, the nature of the bricks or other building material, and the method of conduction ; for example, most houses now have their outer walls separated from the inner by an air space. The problem of such construction is important from the point of view of economy, because the cost of warming a house is obviously greater if much of the heat supplied is being wasted by conduction through the walls.

VENTILATION

Heating and ventilation. This problem of keeping a dwelling-place warm does not exist alone, because for health and efficiency, a room must be adequately ventilated as well as comfortably warmed. A room is well ventilated when the air in it is fresh and pure ; the cold draughts favoured by some " fresh-air fiends " are not necessary and their chilling effect is as harmful as inadequate ventilation. The difficulty that arises is that if ventilation is good, there tends to be a great loss of heat, and either extra heating must be supplied to compensate for this wastage, or else it must be minimised by warming the fresh air admitted. Thus heating and ventilation are intimately connected : the amount of ventilation depends partly on the temperature of the room, and methods of ventilation often depend on methods of heating.

Why ventilation is necessary. Good ventilation is essential because it prevents respiratory and other diseases, and ensures a greater efficiency of work. It is necessary that the air in a room be renewed because it gets contaminated by people breathing and by the combustion of fuel. It will be seen in

Chapter XII that air consists of a mixture of gases in the proportions of 20·96 per cent. of oxygen, 0·04 per cent. of carbon dioxide, 79 per cent. of nitrogen and a small and varying amount of water vapour. When the air is breathed into the lungs, changes take place and the air breathed out consists of 16·4 per cent. of oxygen, 4·1 per cent. of carbon dioxide, 79·5 per cent. of nitrogen and an increased amount of water vapour.

EXPT. 25. **Carbon dioxide expelled during breathing.** Fit up two flasks *A* and *B* as shown in Fig. 63. Fill them half full of lime water, a clear liquid that turns milky in the presence of carbon dioxide. Breathe in and out by the tube at the top, so that inspired air is drawn through the lime water in *A* and expired air is expelled through that in *B*; observe which lime water becomes very milky.

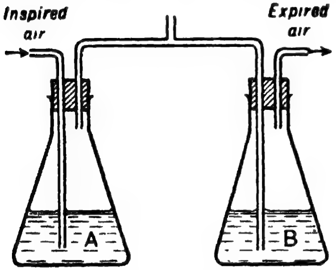


FIG. 63. COMPARISON OF THE CARBON DIOXIDE PRESENT IN INSPIRED AND EXPIRED AIR.

The burning of gas of any kind of fuel also results in an increase of carbon dioxide and a decrease of oxygen. Unless fresh air is supplied, the *excess* of *carbon dioxide* in a room causes a feeling of stuffiness and oppression to the people in it. An added discomfort is due to the *increased moisture* when people are present, because of the continual evaporation from their bodies by means of the lungs and skin. In this way, the air of a room gets more and more saturated, so that normal evaporation from the body is checked, and since evaporation causes cooling, the checked evaporation makes the body feel excessively hot and clammy.

A further source of impurity in the air is the presence of **bacteria**, certain of which cause disease. There are more in a closed room than in the fresh air, and the more dusty and dirty the air, the greater the number of bacteria. The bacterium causing the common cold has not been definitely identified, but

infection is caused by a person coughing and sneezing and so projecting bacteria into the air of a room, when they are breathed in by another person. Much infection thus takes place in crowded and ill-ventilated public conveyances.

A plentiful supply of fresh air is necessary to prevent (1) excess of carbon dioxide, (2) increased moisture, (3) increased bacteria.

Conditions for good ventilation. It has been estimated that every person in a room should have an air space of 1000 c. ft. and should be supplied with from 2000 to 3000 c. ft. of fresh air every hour. The air entering the room should not move at a greater speed than three metres a minute or it causes a draught. The temperature of the air should be from 15° C. to 16° C., and this means there must be more windows open in hot summer weather than in the winter. For good nervous activity, the warmth at floor level must be greater than at head level, because when warm air is breathed, there may be congestion of the nasal passages and a stuffy feeling of the head. The air should be fairly dry, and its relative humidity as tested by the wet and dry bulb thermometer described in Chapter XII, should be about fifty per cent.

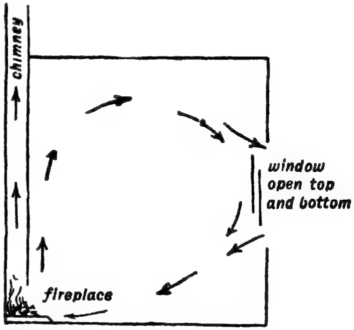


Fig. 64. Ventilation of a Room by Convection Currents caused by a Fire.

In an ordinary room containing only a few people, such conditions can be achieved by *natural* ventilation, that is, a replenishing of the air by convectional movement, and not by movement artificially produced by fans. When a room is heated by a coal fire or a good gas fire, the air is kept in constant motion, impure air and products of combustion rise up the chimney, while fresh air enters by the window and door (Fig. 64). If a window is open at the top and bottom, warm impure air rises and goes out at

the top while cooler and heavier fresh air comes in at the bottom. In any ventilating system there must be openings so that such movement can occur.

Ventilation of a large room. Where rooms are large, or a number of people are congregated in one room, more adequate ventilation is required than that obtained from a chimney, windows and door.

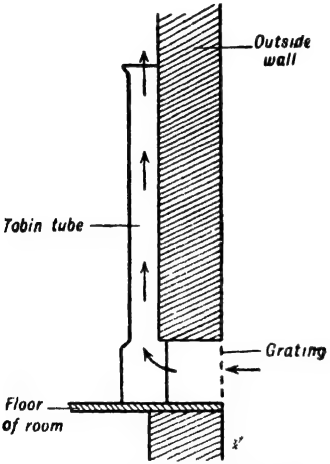


Fig. 65. Tobin Tube Type of Air Inlet.

The air passes into the room at a height of 5 ft. or 6 ft.

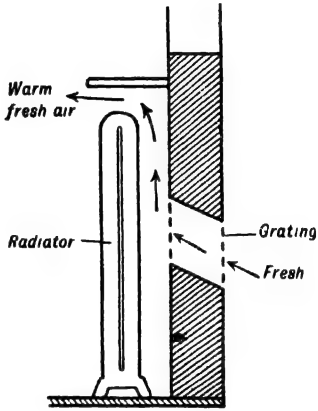


Fig. 66. Incoming Air warmed by a Radiator.

The shelf above the radiator prevents the dust in the warmed air blackening the wall.

Special outlets are wanted for the impure air, and these may take the form of gratings placed near the ceiling or openings beneath the cornice connected either to the outside air or to the flues. To prevent down draughts from such outlets, they should have light flap valves of oiled silk, so that air can only pass in one direction out through them.

Fresh air inlets should be halfway up the walls so that draughts are not caused at floor level. In the Tobin tube type

of inlet, air passes vertically up into the room at a level of 5 ft. or 6 ft. (Fig. 65). If the room is heated by central heating, the incoming air can be warmed by letting it pass through gratings behind radiators (Fig. 66).

HEATING

Methods of heating. The various methods of heating buildings are by coal, gas and electric fires and by central heating. Each type of heating has its advantages and disadvantages and probably the ideal method of heating a house is by moderately warm central heating to minimise the chill of the rooms, and then open coal fires for appearance and comfort in sitting-rooms.

The coal fire. The modern coal grate has no bars in front and is placed low on the hearth. The best radiating efficiency is obtained with a low, wide and shallow fire. The fireplace is surrounded with firebrick, a non-conductor of heat, and this is inclined at the sides and back ; the side inclination ensures that a greater area of the room receives direct radiation, and the back inclination reflects radiant heat back into the room that would otherwise pass up the chimney. The inclination of the back, furthermore, makes the combustion of the fuel more complete because the hot firebrick helps to ignite the products of combustion. Fig. 67 shows a modern fireplace of good construction ; in this type the actual fire is placed on blocks of fireclay and not

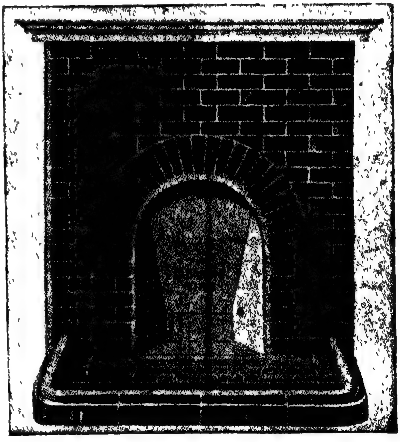


FIG. 67. A MODERN COAL GRATE.
(*By courtesy of Candy & Co. Ltd.*)

on iron bars, so that less heat is conducted away and more complete combustion of the fuel takes place.

The chief advantages of a coal fire are: (1) it has an attractive appearance, (2) it causes a circulation of air and assists ventilation, (3) it is the cheapest to use when a fire is required for a long period of time, (4) it heats the room by radiation, so that the air is kept cool and of the right humidity.

Its chief disadvantages are that it causes dirt and extra labour, and that much of the heat passes up the chimney by convection and is wasted.

The gas fire. In the gas fire, a row of burners heat fireclay radiants and the latter on becoming red-hot radiate heat to the room. A good modern type of fire (Fig. 68) has two openings under the canopy, up one of which pass the products of combustion and up the other air from the room; these openings join higher up, and the movement of the air is thus largely due to that of the products of combustion. With such adequate ventilation there should be no unpleasant fumes from a gas fire. The chief advantages of a gas fire are that it is clean and labour-saving and can conveniently be used for short periods of time; it is the cheapest form of fire for occasional use as, for example, in a dining room.

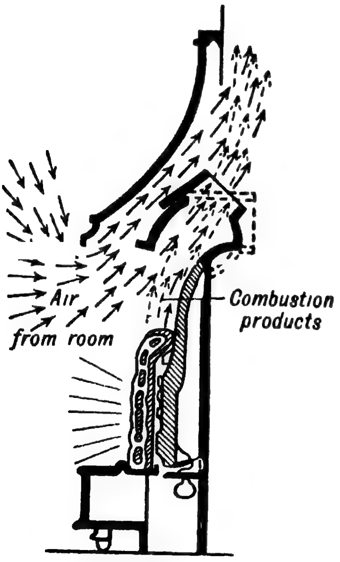


FIG. 68. A MODERN GAS GRATE WITH SPECIAL VENTILATING OPENING.

The electric fire. The heating effect of an electric current will be considered more fully in Chapter IX. The heating elements of a fire are of nichrome wire, which is made red-hot

by the flow of electricity through it, so that it radiates heat to the room. A good form of mounting is shown in Fig. 69, where the spirals of wire lie in small fire-clay wells which assist in the radiation of heat in all directions. The advantages of an electric fire are that it is easily portable; like the gas fire it is clean and labour-saving and convenient for using for short periods of time.

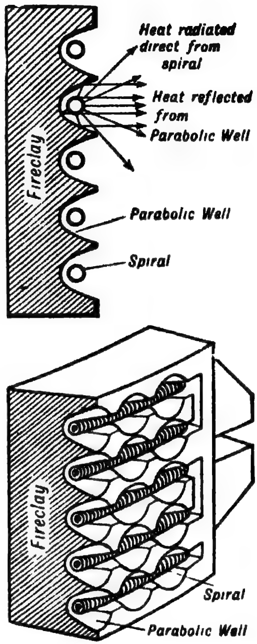


Fig. 69. A Good Method of Mounting the Heating Elements of Electric Fires.
(*By courtesy of Belling & Co.*)

Central heating. Some form of central heating is the most economical method of heating large buildings, because only one fire is required to heat the boiler. The fuels generally used are anthracite and coke; of these, coke is the cheaper to use. The water from the boiler circulates round the house by convection as described on page 72, and by means of radiators heat is given to the rooms. Actually most of the heat given out by so-called radiators is by convection; the air above them becomes warm and rises and so by convectional circulation of the air, the heat is distributed through the room. This method has the disadvantage that an atmosphere of warm air is not hygienic and tends to cause a feeling of stuffiness. Consequently the more modern forms of central heating attempt to obviate this by arranging behind walls and ceilings hot water pipes in which water circulates at only 80°–90° F. The heat then passes mostly by radiation from the large areas of surface so heated. Fig. 70 shows a room in which there is such a heating arrangement behind oak panels.

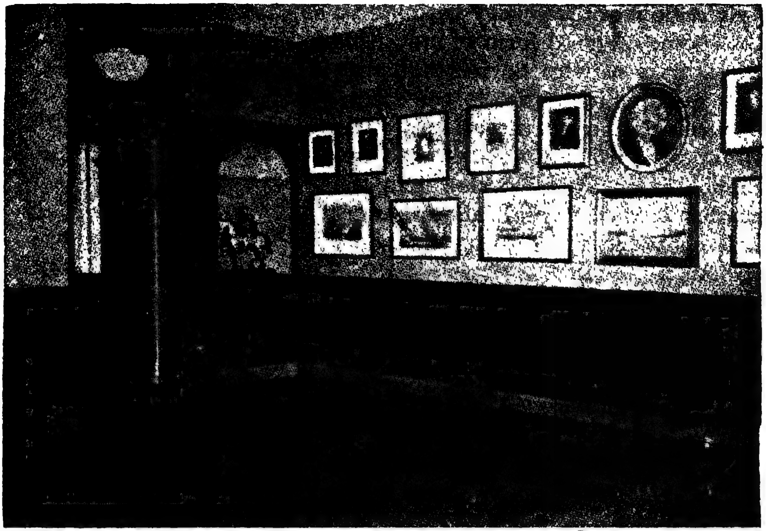


FIG. 70. ROOM FITTED WITH IDEAL RAYRAD.
There are hot water pipes behind the oak panelling.
(*By courtesy of the National Radiator Co. Ltd.*)

A similar type of continuous warming of large buildings can be obtained electrically by tubes or panels containing heating elements, which work at a much lower temperature than those of electric fires. The latest form of low temperature panel consists of a flexible fabric containing a net of resistance wire. This fits over the surface of the ceiling and works at a temperature of between 80° and 100° F.

CHAPTER VI

LIGHT AND SOUND PROPAGATION. ECLIPSES. REFLECTION. ECHOES. ACOUSTICS

Light and sound. It has already been seen that light, like heat and wireless, consists of ether-waves. These waves are of various lengths (Fig. 71) and the values for wireless waves of several hundred or a thousand metres are familiar to everyone. Light waves, on the other hand, have a very short wave-length of only a few hundred-thousandths of a centimetre. When they fall on the **retina**, a network of sensitive nerves at the back of the eye, a sensation of light is produced, or if the waves fall on a photographic film or a green leaf, a chemical effect occurs.

Sound also consists of waves, but their nature is very different from that of light. A sound is produced when a body vibrates ; if a sounding tuning-fork or bell is held against the lips, its vibrations can distinctly be felt. Sometimes the vibration is rough and irregular as when a book falls to the ground, and the sound is then described as a *noise* ; sometimes it is regular and harmonious, as when a violin string is plucked, and it is then called a *musical note.* The more rapid the vibrations, the higher the pitch of the note. The vibrations to and fro of the body producing the sound stir the particles of air in contact with it, and in this manner, waves of sound, consisting of a similar movement of particles of air, travel out in all directions from the sounding body.

Light, then, is of a type of ether-waves known as electromagnetic waves, which can travel through space at a tremendous speed ; sound consists of vibrations in the air or some

other kind of matter, and such waves travel comparatively slowly. Sound can only travel if there is a material substance

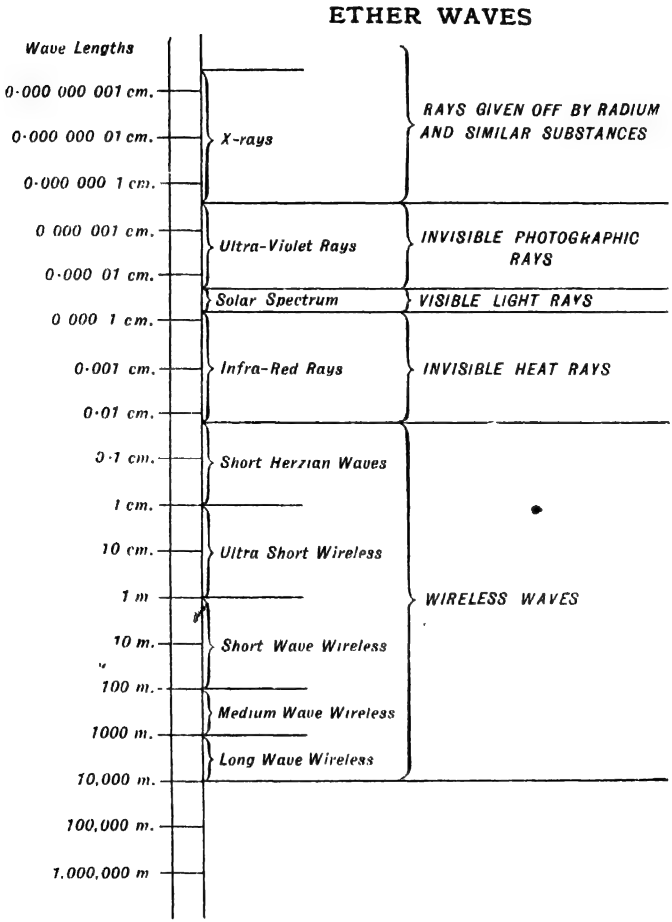


FIG. 71. A TABLE SHOWING THE VARIOUS KINDS OF ETHER-WAVES.

to transmit the waves; it cannot pass through space. Hence if there were tremendous noises due to disturbances on the sun,

we should not hear them, although we could continue to see the sun and feel its warmth. The light and heat would reach us, but not the sound.

Difference in speed of light and sound waves. In Chapter I, it was seen that the great distances between the earth and the stars makes it necessary to measure in light-years, that is, the distance light, travelling at 186,000 miles per second, can travel in one year. Even so, light may take thousands of years to pass from a star to the earth. But on the earth itself, distances are negligible compared with the immensities of interstellar space, and the speed of 186,000 miles a second means that light seems to pass instantaneously from one point to another. If a gun is fired a mile away from an observer, the light of the flash takes only $\frac{1}{186000}$ of a second to travel to him, so he may be said to have seen it instantaneously. Sound, however, only travels at about 1100 feet per second in air, so that the sound of the shot would take $\frac{5280}{1100}$, or nearly five seconds, to travel the distance of one mile to the observer. He would, therefore, see the flash, and hear the sound of the shot five seconds later.

Many examples of this phenomenon occur in everyday life. Unless a thunderstorm is immediately overhead, there is an interval between the lightning and the thunder, although the thunder, which is the crackling noise of the electric spark, actually occurs at the same time as the flash. If a cricket match is being watched from some distance away, the bat is seen to strike the ball a second or two before the sound of the impact is heard, and a similar effect occurs with a golf ball. At a Military Tattoo, when soldiers are marching with a band, they appear to be out of time with the band as they recede, but actually their movements are being seen practically at the instant they occur, while the sounds of the band take an appreciable time to reach the onlooker.

Sound waves in different media. Sound travels through water and other liquids at a much greater speed than through

air. This can be demonstrated by listening with one ear at a long stretch of iron railing while a friend strikes the railing sharply some distance away. The sound is heard twice ; first by the ear that receives it through the railing, and later by the ear listening in the air. The earth is a very good medium for transmitting sound, and everyone knows the device so popular in Red Indian games of listening for footsteps with an ear to the ground ; they can be heard even when a great distance away. A simple experiment to illustrate the same point is to place a watch at one end of a long rod (Fig. 72) ; it can be heard ticking

FIG. 72. HOW A WATCH CAN BE HEARD TICKING THROUGH A WOODEN ROD.

through the wood even although it cannot be heard at the same distance away in air. In the same way, the water pipes of a house often carry sound and a " hammer " is heard in them when a tap is opened and closed in another room.

Variations of intensity of light and sound. In the case of both light and sound, the intensity diminishes considerably with distance from the source, because the energy of the waves travelling out in all directions must be spread over so much greater a surface. The intensity at a particular point depends on two things—(1) the illuminating power of the source of light or the loudness of the sound, and (2) the distance of the point from the source of light or sound.

The illuminating power, or candle-power, of a light is judged by the light it gives out compared with a *standard candle*, that is, a candle made of spermaceti wax burning 120 grains per hour. Actually, nowadays, lamps are compared, not with a candle but with a *standard pentane lamp*, which is equal to 10 candles. Thus a 100 C.P. electric lamp is one which gives out ten times as much light as the 10 C.P. standard lamp. The loudness of a sound depends on the amplitude of vibration of

the sounding body, that is, the extent of its motion from its position of rest. Thus a violent vibration produces a loud sound, but it must be remembered that the rapidity of a vibration determines the pitch of the note, and not its loudness.

However, the intensity of light or sound depends on distance as well as on the brightness of the light or the loudness of the sound. The intensity of illumination of a surface by light is measured in *foot-candles*, 1 foot-candle being the illumination produced on a white screen held vertically at a horizontal distance of 1 foot from a standard candle. Illumination de-

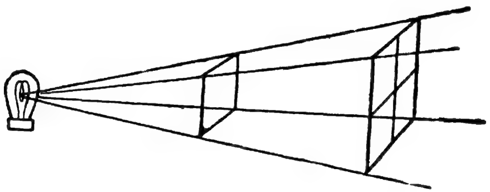


FIG. 73. WHEN THE DISTANCE OF A SCREEN FROM A LAMP IS DOUBLED, THE SAME AMOUNT OF LIGHT HAS TO ILLUMINATE FOUR TIMES AS GREAT AN AREA.

creases very much with distance, because if a screen is moved twice as far away from a lamp the same amount of light has to illuminate four times as great an area (Fig. 73). (It is assumed that light travels in straight lines.) Thus a 10 C.P. lamp placed 1 foot from a white screen produces 10 foot-candles of illumination, but if moved to a distance of 2 ft., it only gives a quarter of that illumination, that is, 2·5 foot-candles. To avoid eye-strain there should always be 3 foot-candles of illumination in a sitting room where people are reading. For dark needlework at least 8 foot-candles are required and preferably an extra lamp should be placed near the needlewoman.

The variation in the intensity of sound depends on weather conditions as well as on distance; temperature, wind and fog affect the speed and intensity of sound.

Rectilinear propagation of light. In Fig. 73 it was assumed that light waves seem *to travel in straight lines.* A beam of light from the sun or in a cinema always looks straight, but actually the light itself is invisible, and the path of the light is only seen, because of the reflection that occurs from particles of dust in the beam. If cigarette smoke is blown into the beam, the path of the light becomes still more visible.

EXPT. 26. **Light travels in straight lines.** Take three cards and pierce a fine hole in each. Attach them with rubber bands to blocks of wood, so they are supported vertically. Place a lighted

FIG. 74. LIGHT TRAVELS IN STRAIGHT LINES.

candle in front of the first card, place the other two so that the holes are in a straight line, and look through at the light of the candle (Fig. 74). Move the middle card to one side, and note that the light can only be seen when the holes are in a straight line.

These straight paths along which light waves travel are called rays of light. When a ray seems to be visible it is because we can see dust particles among which the wave of light follows a straight course.

A difference that occurs with sound waves, is that they behave differently from light by bending round when they encounter an obstacle in their path. If a bell and an ear were substituted for the lamp and the eye in Experiment 26, the sound of the bell ringing would reach the ear, because some waves might bend round the screens, or be reflected back from the walls nearby. Two people on opposite sides of a wall can talk, although they cannot see each other.

Shadows. One consequence of the propagation of light in straight lines is the formation of the shadows. Rays of light

coming from a luminous body do not bend round on meeting an obstacle, and so there is a region behind it where there is no illumination, and this is called **umbra** or total shadow. Other places will receive partial illumination, and such a region is called **penumbra** or partial shadow. If an eye is placed in the umbral region, the source of light cannot be seen, but from the penumbral region it is partly visible.

EXPT. 27. **Variation of umbra and penumbra of shadows.** Use a small round tin lid as an obstacle. Take two cardboard

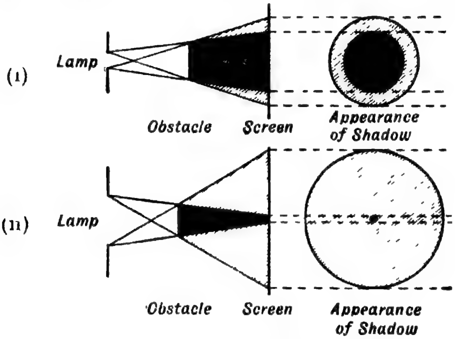


FIG. 75. THE UMBRA AND PENUMBRA OF TWO SHADOWS.

screens; in one, make a very small hole, and in the other a hole bigger than the obstacle. Support the screens in turn in front of an opal electric lamp, and place the obstacle and a plain screen at suitable distances away. Observe the variation in umbra and penumbra of the shadows in the two cases as the screen is moved.

The effect is shown by the rays coming from extreme points of the source of light. In Fig 75 (i) it can be seen that umbra and penumbra increase as the screen is moved away, the penumbra more rapidly. In Fig. 75 (ii) the umbra decreases, while the penumbra increases.

Eclipses. The most interesting examples of such shadows are the eclipses of the moon and of the sun. Both kinds of eclipse are caused by shadows of the second type just described, because the source of light, the sun, is much larger than the

obstacle, whether it be the earth or the moon. When the moon passes into the shadow of the earth, an **eclipse of the moon** occurs (Fig. 76) and this is total or partial according to whether the moon is in the umbral or penumbral shadow ; more

FIG. 76. ECLIPSES OF THE MOON—PARTIAL AND TOTAL.

often it is the latter. The eclipse can only occur at full moon when the moon is on the side of the earth remote from the sun.

An **eclipse of the sun** occurs when the moon passes between the sun and the earth (Fig. 77), so that regions in the umbral shadow experience a complete eclipse of the sun, and those in the penumbral shadow can always see part of the sun. In

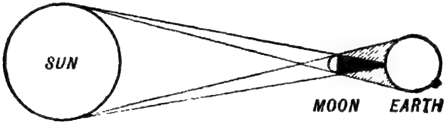


FIG. 77. AN ECLIPSE OF THE SUN.

places of total eclipse, at the time when the moon completely covers the sun, unusual phenomena such as crimson flames, and a silvery aura, called the solar corona, make a unique spectacle. Astronomers find a total eclipse valuable for studying effects that cannot be viewed under ordinary conditions of sunlight. The solar corona, for example, can only be observed during a total eclipse of the sun.

REFLECTION

Reflection. When light or sound fall on a surface some may be absorbed, but with certain surfaces, nearly all is reflected.

EXPT. 28. **Reflection of light and sound.** Take two long tin tubes about 4 ft. long and 3 in. in diameter and set them in

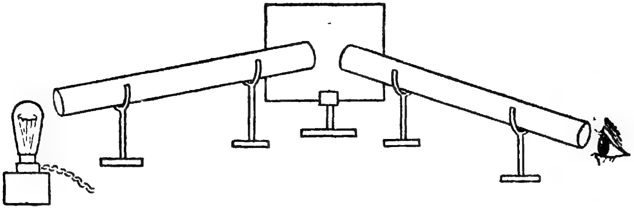


FIG. 78. AN EXPERIMENT TO SHOW THE REFLECTION OF LIGHT AND SOUND.

stands making an angle of about 120° with each other Where they meet, place a polished metal sheet, and at the end of one set up an electric lamp (Fig. 78). Look along the second tube, and adjust the position of the metal sheet, so that the lamp is viewed by reflection. Note the inclination of the tubes with regard to the reflector. Now substitute a watch for the lamp, and listen at the second tube. Even if the watch can be heard directly the sound of the ticking is much more distinct when the reflector is in position.

Next place the tubes in a straight line end to end. The watch cannot be heard at a distance of 8 ft. in the air, but when placed at one end of the tubes, it can be heard clearly at the other end.

The last part of the experiment illustrates the principle of a speaking tube or a megaphone; repeated reflections from the walls of the tube prevent the sound waves spreading and concentrate them in one direction. In a large church a sounding board is often used above the pulpit; this reflects the sound waves down so that a greater concentration of waves reaches the congregation.

Both light and sound are reflected regularly from a smooth surface at an angle equal to that at which they strike the reflecting surface. This can be shown more accurately with light by using actual rays and a mirror.

EXPT. 29. **Reflection of light and position of the image formed.** Set up a plane mirror vertically on a sheet of paper. Arrange a metal filament lamp behind a narrow slit in a metal screen to obtain several rays of light across the paper. With a pencil mark the position of the mirror and the direction of the rays before and after reflection.

A line at right angles to the mirror at the point where a ray strikes the mirror is called the **normal**; the ray of light is the **incident ray** and the reflected one traced out is the **reflected ray.** Draw in normals on the drawing paper and measure the angles between the incident ray and the normal and the reflected ray and the normal,

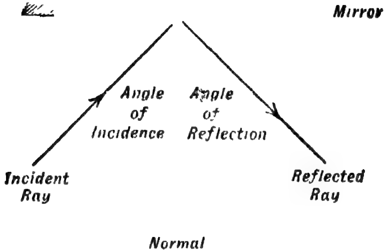


FIG. 79. THE ANGLE OF INCIDENCE OF A RAY OF LIGHT IS EQUAL TO THE ANGLE OF REFLECTION.

i.e. the angles of incidence and reflection (Fig. 79). Tabulate the results in two columns:

Angle of incidence	Angle of reflection

The numbers in both columns should be equal.

Produce the lines of two reflected rays back to intersect behind the mirror. The point of intersection shows where the image of the slit appears to be when viewed in the mirror. Drop perpendiculars from the point to the line of the mirror, and from the point where the incident rays emerge from the slit. Measure these distances. They should be approximately equal.

This experiment verifies the **laws of reflection** of light which are (i) *the incident ray, the normal and the reflected ray all lie in the same plane, and* (ii) *the angles of incidence and reflection are equal.*

Image formed by plane mirror. When an image is seen in a plane mirror, it appears to be behind the mirror. It is called a *virtual image,* because no rays actually pass through it; the

reflected rays merely seem to come from it when they enter the eye from that direction. Experiment 30 *showed that the image is as far behind a plane mirror as the object is in front.* Knowing this fact it is quite simple to draw a diagram to show how an eye observes the image. In Fig. 80 the object is shown, and then the image is placed at an equal distance behind the mirror. Divergent beams of light which seem to come from the image are shown entering the eye, but actually such beams have come from the object and been reflected.

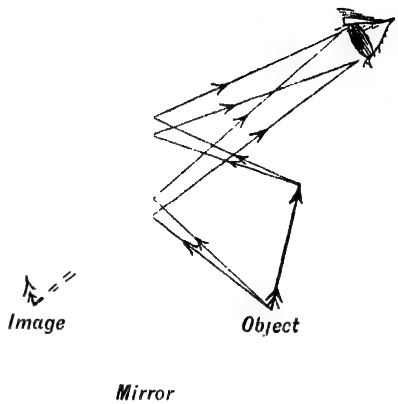


Fig. 80 How an Image is seen in a Plane Mirror

One curious effect produced in a mirror is that of **lateral inversion.** If a girl parts her hair on the right hand side, she will find that the reflection she views in the mirror has hair parted on the left ; if she raises her right hand, the image in the mirror raises her left. If printing is held in front of a mirror all the letters seem to be turned round as in Fig. 81.

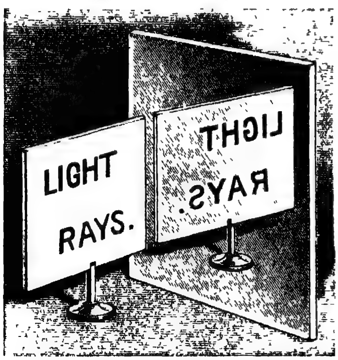
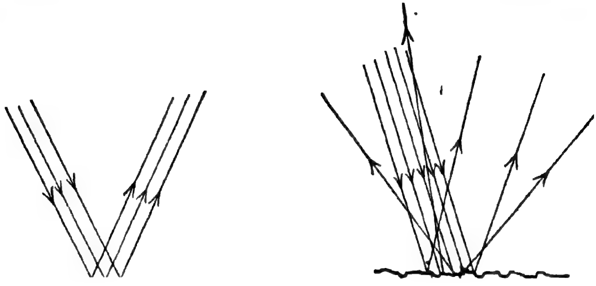


Fig. 81. An Example of Lateral Inversion.

Diffused reflection. Objects are visible in the world around us, solely because light is reflected from them into our eyes. If, however, the reflection were of the regular kind already considered, things could only have been seen from one position, that is, from the direction of the reflected beam (Fig. 82 (i)).

Actually, however, owing to the roughness of the surface of most objects, light is *diffused* or reflected irregularly as shown



(i) (ii)

FIG. 82.

(i) Regular reflection of light from a very smooth surface.
(ii) Diffused reflection of light from an ordinary surface.

in Fig. 82 (ii). It still follows the laws of reflection, but owing to the rough surface, each ray has a different angle of incidence and so all the angles of reflection vary and the rays are scattered. This effect may be produced even in transparent substances, as for example, when a halo is seen round the moon, because the moonlight is reflected in a scattered way from tiny drops of water in the air.

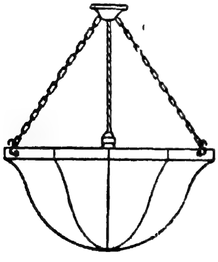


FIG. 83. AN ALABASTER BOWL FOR DIFFUSING LIGHT.

This principle of **diffusion** is of practical value in all modern methods of indirect lighting of buildings. When the light of a lamp is concentrated over a very small area, it may be so bright as to produce a blinding effect known as **glare**; the filament of an electric lamp, for example, is dazzling if looked at directly, and such glare is injurious to the eyes. Modern designs in lighting aim, therefore, at distributing and diffusing the light so that it emanates from a fairly great area evenly. The china and alabaster bowls placed under gas and electric lights (Fig. 83),

diffuse the light most effectively, and since some of the light is reflected up to the ceiling from where it is reflected down again to the room a good distribution of light is obtained.

Echoes. It has been seen that sound waves are reflected similarly to light waves. If a sound wave falls perpendicularly on a large flat surface, it is reflected back along its own path, because both the angles of incidence and reflection equal zero. In such a case, the slow speed with which the sound travels will cause an appreciable time to elapse between the original sound and the arrival of the reflected wave, and so an **echo** is heard. To obtain a good echo, a perpendicular wall or cliff is necessary to ensure reflection back along the same path and also the source of sound should be sufficiently far from the reflecting surface for the original and reflected sounds not to be confused.

If a person standing 100 ft. from a cliff calls out, the sound has to travel 100 ft. to the cliff and 100 ft. back again, making 200 ft. in all. Since sound travels at 1100 ft. per second, it will cover this distance in about $\frac{1}{5}$ of a second. A good echo would not be obtained at much less a distance.

The variation in the sound of a car when going across an open moor and between high walls is due to the reflection of sound waves; between walls there is much more noise than in the open. There is a similar difference when a train is on an embankment and in a tunnel. The sound of a church bell will sometimes seem to come from quite the wrong direction if it is reflected from the walls of the houses.

Acoustics. The reflection of sound from walls is of the utmost importance in the construction of large halls and buildings. Everyone is familiar with the loudness and resonance the voice seems to have when anyone sings in his bath; the bare walls of a bathroom are excellent reflecting surfaces, and the sound echoes to and fro. An expanse of bare walls in a church or a large hall may cause inconvenient echoes to a speaker. The broadcasting rooms of the B.B.C. are specially designed to meet

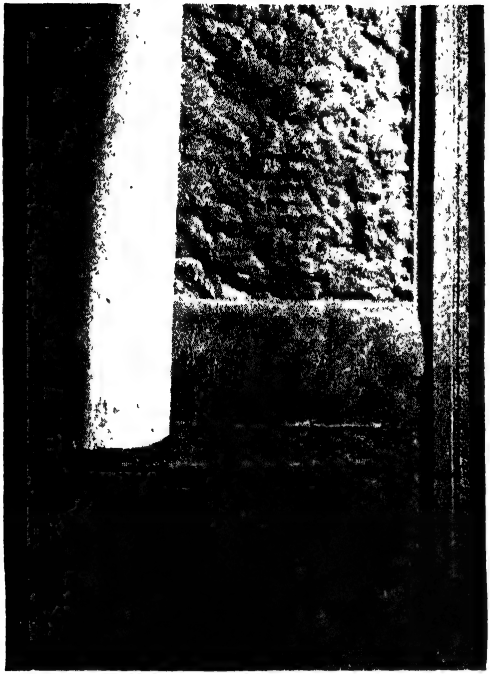


Fig. 84. A Method of treating Studio Walls with Sound-absorbing Wool to make them acoustically "Dead."
(By courtesy of the B.B.C.)

this difficulty and some, such as that from which news is broadcast (Fig. 84), are made acoustically "dead", that is, there is no echo whatever in them; others, such as the concert hall, have a comparatively long echo period.

Often in a large hall, a microphone is placed in front of the speaker, so that the sound is transmitted electrically to the loud speakers in the hall. The principle is somewhat similar to that of the telephone as explained in Chapter VIII. The loud speakers are placed in such position that echoes are avoided, but a little distortion of the voice seems unavoidable.

CHAPTER VII

REFRACTION OF LIGHT. LENSES. CAMERA. EYE. SPECTACLES. COLOUR. RAINBOW

Refraction. The twinkling of a star, the apparent bending of a stick in water, the wavy appearance of objects seen over a hot tarred road, are phenomena due to the bending, or **refraction,** of rays of light when passing from one transparent medium to another. In one particular medium, the light travels in straight lines, but if it passes to another of different density—in the case of the star and the road, a variation of cold and warm air—it bends at the surface of separation of the two media, and then goes straight on again in the second medium.

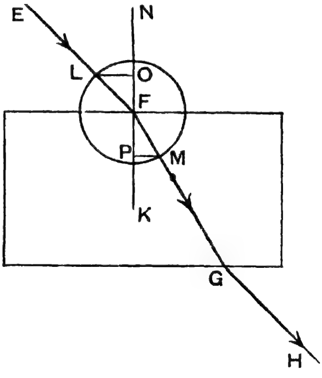


FIG. 85. A RAY OF LIGHT IS BENT ON PASSING THROUGH A SLAB OF GLASS.

EXPT. 30. **Refraction of light on passing from air to glass.** Place a slab of glass on a sheet of drawing paper, and let rays of light obtained as in Experiment 29, pass through it. Mark the position of the glass on the paper, and a particular set of incident and emergent rays, EF and GH (Fig. 85). Remove the glass and join up the points F and G where the ray enters and leaves the glass. EF is an *incident ray* and FG is a *refracted ray* in the glass. Through F draw a normal NFK. Then EFN is the *angle of incidence* and KFG is the *angle of refraction*. Measure these angles. With centre F and any radius, draw a circle cutting the incident ray at L and the refracted

ray at M. From L and M, drop perpendiculars LO and MP on to the normal. Measure LO and MP. Carry out a similar construction and measurement for rays incident at different angles. Tabulate results thus:

Angle of incidence	Angle of refraction	LO	MP	$\frac{LO}{MP}$
		cm	cm.	

The experiment shows that for rays passing from air to glass the angle of refraction is smaller than the angle of incidence, *i.e.* the rays are bent *towards* the normal. The direction of the rays could be reversed and then rays passing from glass to air would be bent *away* from the normal. The ray is always nearer the normal in the more dense medium.

The numbers in the last column in the experiment should be a constant and equal to 1·5. Such a constant is the **refractive index** for any given substance. Thus for glass, its value is 1·5 or $\frac{3}{2}$: for water it is 1·33 or $\frac{4}{3}$.

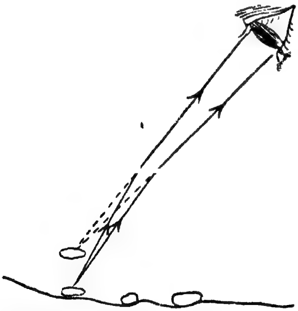


Fig. 86. A Pond appears more shallow than it really is.

Real and apparent depth. Although rays of light are bent in this fashion, the eye cannot be aware of it, and if light enters the eye from a certain direction, the object appears to be in that direction. In this way, an illusion is created, and a pond seems to be more shallow than it actually is (Fig. 86); rays from objects at the bottom of the pond are bent away from the normal on passing into the air, and the direction in which they enter the eye makes them appear higher up. Thus a stick appears bent because the bottom of

it seems to be raised. If a penny is placed in such a position in a trough so that it is hidden by the edge of the bowl when it is empty, it becomes visible when the trough is filled with water. The glass slab used in Experiment 30 may be placed with its shortest side on some printing; on looking down through it, the words will seem to be very much raised. There is a definite simple connection between real and apparent depth. It is that:

$$\frac{\text{real depth}}{\text{apparent depth}} = \text{refractive index.}$$

For water this is $\frac{4}{3}$, so that a pond 4 ft. deep appears to be only 3 ft. deep, that is, three-quarters of its actual depth.

Critical angle. It has been seen that rays emerging from a dense to a less dense medium as, for example, from glass to air, are bent away from the normal. At a certain value for the angle of incidence, (the **critical angle**), the angle of refraction will be 90°, and the emergent ray will just graze the surface of separation of the media (Fig. 87). For glass the critical angle is 42° and for water 49°. Rays that strike the surface at an angle greater than the critical angle do not pass out, but are *totally reflected*; the surface acts as a perfect mirror.

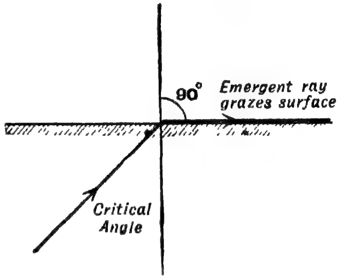


FIG. 87. A RAY, INCIDENT ON A SURFACE AT THE CRITICAL ANGLE EMERGES AT AN ANGLE OF REFRACTION OF 90°.

This effect can be seen very simply. If a sixpence is placed in a tumbler of water, and the tumbler is held up in a good light, so that the under-surface is viewed obliquely (Fig. 88 (i)) an image of the sixpence can be seen reflected in a surface that shines like mercury. Rays that should emerge from the water to the air are incident at an angle greater than 49° and are totally reflected. An optical illusion of a test tube appearing

to be full of mercury may be achieved by placing an *empty* test tube in a beaker of water (Fig. 88(ii)). In this case the brilliance of the totally reflected light gives the illusion of mercury in the test tube. which is sometimes seen in England is the drops of H_2O on the vessel

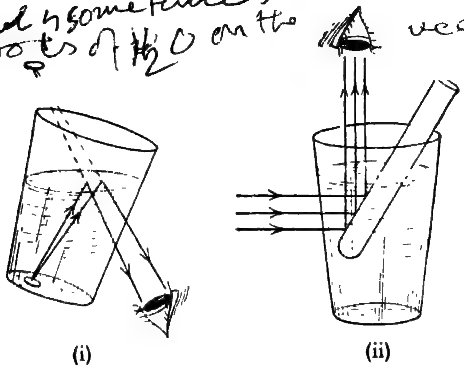


FIG. 88. OPTICAL ILLUSIONS DUE TO TOTAL REFLECTION.

Mirage. A mirage sometimes seen in England is the illusion of pools of water on the road ahead when motoring in very hot weather. The effect is due to a layer of warm air (a less dense medium than cooler air) remaining near the hot road, so that oblique rays of light are totally reflected at the surface of separation of this and the colder air above ; consequently the motorist sees the shining effect of water. Such layers of air frequently move, and the different refractivity of the various streams of air results also in the wavy appearance of objects seen through them. The mirage seen in the desert is similar to that on the road ; the hot sand has a layer of hot air in contact with it, which causes total reflection, and movements of the air may cause weird images which appear to be palms and ripples on the water.

Prisms. The rays of light traced through a slab of glass in Expt. 30 were bent on entering and leaving the glass, but their final direction was parallel to the original one. With a prism the effect is different.

Expt. 31. Refraction of light by a prism. Set up apparatus as in Experiment 30, but trace the path of rays of light through prisms of different angles. Note that the rays are slightly coloured on emergence. Take a prism with angles of 45° and try to find positions in which total reflection of light occurs.

In every case, light is *bent towards the base* of the prism. The angle of deviation (EFC in Fig. 89) is the angle between the

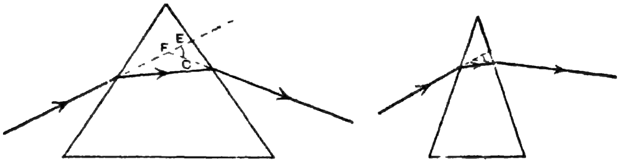


Fig. 89. Refraction of Light by Prisms.

incident ray and the emergent ray, and this is greater with a prism of greater angle. The effect of colour seen in the emergent ray will be discussed more fully later in the chapter. A prism with angles of 45° can be used for the total reflection of light

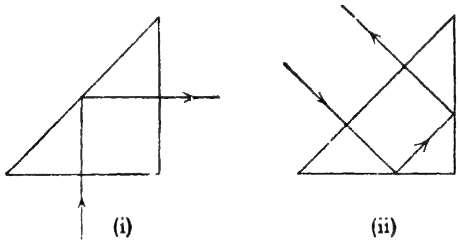
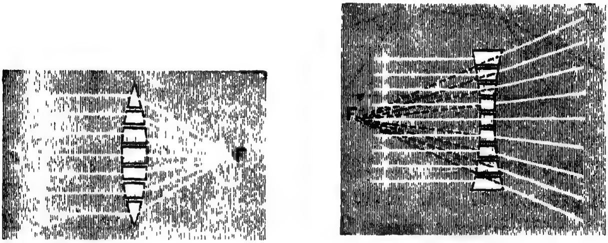


Fig. 90. Total Reflection of Light by a Prism (i) through 90°. (ii) through 180°.

at 90° and 180° (Fig. 90) and prisms are used in this way in periscopes and prismatic binocular field-glasses.

Lenses. Everyone is familiar with the lenses used for spectacles or magnifying glasses; they are pieces of glass with curved surfaces. Their action on rays of light may be understood by regarding them as being built up of parts of prisms. A **converging** (or convex) lens is thicker in the middle and the

angles of the prisms increase towards the edges (Fig. 91 (i)). Thus, if a number of rays are refracted towards the bases of the prisms, those at the edges are deviated most and bend inwards, while a ray at the centre meets a parallel-sided piece of glass normally and goes straight on. Thus all the rays converge and pass through a certain point. If the incident rays are *parallel* this point is called the **principal focus** (F) of the lens (Fig. 91); its distance from the centre of the lens is the **focal length.**



(i) (ii)

FIG. 91. PARALLEL RAYS FALLING ON (i) A CONVERGING LENS. (ii) A DIVERGING LENS.

A **diverging** (a concave) lens is thinner in the middle, and the prisms are arranged with their bases outwards (Fig. 91 (ii)). Thus rays of light are deviated outwards, and diverge after passing through the lens. In this case, parallel incident rays only *appear* to have passed through the point that is the focus of the lens (Fig. 91 (ii)), and like the image in a plane mirror, the point is virtual or unreal, because rays do not actually pass through it.

To obtain a parallel beam of light the sun's rays may be used. These can be considered parallel, because any that diverged would not strike the small area of a lens after travelling 93 million miles; they would be miles apart by the time they arrived. Thus the small beam used can be considered parallel.

EXPT. 32. **Focal length of a converging lens.** Take a lens out-of-doors and move it about until an image of the sun is formed

on a screen held a short distance from it. If the sun is hidden, obtain an image of the clouds instead ; they are sufficiently distant for rays from them to be approximately parallel. Measure the distance from the lens to the screen, that is, the focal length of the lens.

Images formed by a converging lens. If a converging lens is moved about, it will soon be found that the images made by it on a screen vary with the position of the object.

EXPT. 33. **Variation in nature and position of image formed by a converging lens.** First find the focal length of a converging lens as in the previous experiment. Let this be a distance f. Place the lens in a holder and arrange a candle on one side of it as object and a screen on the other side. Adjust the distance between the candle and the lens, so that it is more than twice the focal length, that is, greater than $2f$, and similarly for the other distances in the table below. Move the screen until a well-defined image is obtained in each case ; measure its distance from the lens and express the distance in terms of f. The results should be as shown in the table below.

In the last case, when the candle is at a distance less than the focal length of the lens, remove the screen and look *through* the lens to observe the image. It will be seen erect and magnified ; the lens acts as a magnifying glass as shown in Fig. 92.

FOCAL LENGTH OF LENS = cm. (f).

Distance of object	Distance of image	Description of image
Greater than $2f$.	Between f and $2f$.	Real, inverted, diminished.
$2f$.	$2f$.	Real, inverted, equal.
Between $2f$ and f.	Greater than $2f$.	Real, inverted, enlarged
At f.	No image.	Parallel rays.
Less than f.	No image on screen.	Virtual, erect, enlarged.

All the images obtained on the screen are *real*, because rays actually form the image in that position. In the last case, no

image is formed on the screen because the object is so close that rays diverge on emerging from the lens ; they only *appear* to come from the image and so it is a virtual one. If the experiment were performed with a diverging lens, all the images would be of this latter type, because the emerging rays always

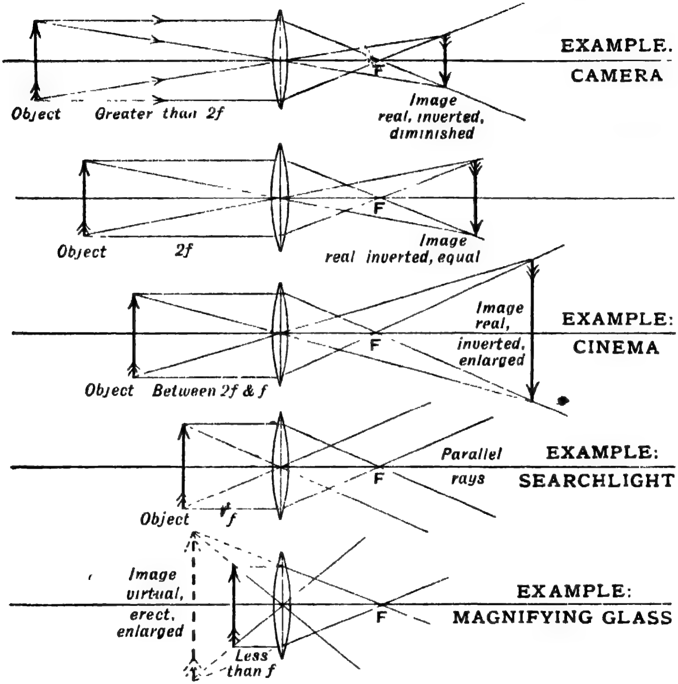


FIG. 92. DIAGRAMS TO SHOW THE FORMATION OF IMAGES BY A CONVERGING LENS.

diverge. No images can be obtained on a screen, but on looking through the diverging lens, erect and diminished images can be seen.

Geometrical construction to obtain position of images. The position of images can be found by a graphical construction. Every lens has a **principal axis**, that is, the straight line drawn

Not a parallel ray

through the centre of the lens perpendicular to both its spherical surfaces. Now two important facts are known :

(1) that a ray parallel to the principal axis passes through the focus on emerging from the lens ; the eminates

(2) that a ray passing through the centre of lens goes straight on without deviation.

When such rays pass through the ends of an object, their direction on emergence is known, and where they intersect must be

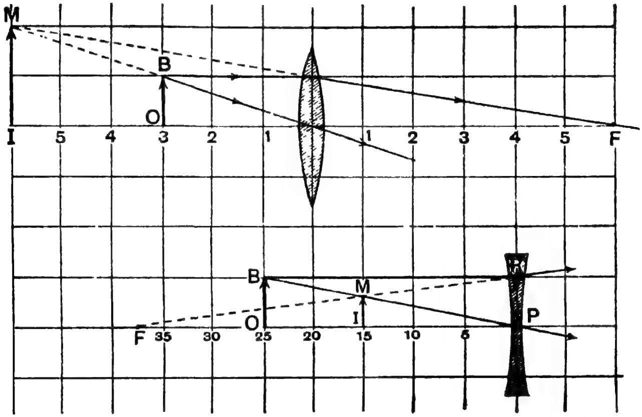


Fig. 93. Graphical Method of solving Problems on Lenses.

In (i) the position and size of the image IM is found, the object OB and the focus F being known. In (ii) the focal length of a diverging lens which will enable a short-sighted eye to see an object OB in the position of the image IM.

the position of the image. A set of diagrams can therefore be made to illustrate the last experiment (Fig. 92). If actual numerical values are given for distances, problems on lenses can be solved by using squared paper, and carrying out constructions in which use is made of the two special rays mentioned above. In Fig. 93 (i) the position and size of the image formed by a magnifying glass is found, and in Fig. 93 (ii) the focal length of a diverging lens required to correct short sight. In the latter case, the position and size of the object OB is drawn

in first and then the ray BP indicates the size of the image MI at 15 cm. from the lens. The ray BR parallel to the principal axis would appear to come from M, so that RM produced backwards, gives the position of the focus.

The camera. In the camera, a converging lens is used to form real, inverted, diminished images on a sensitized plate or

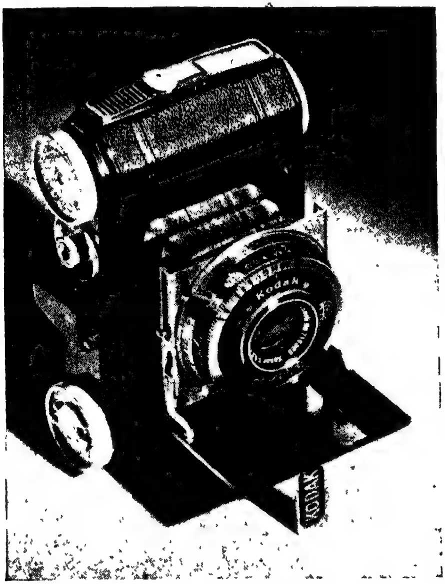


FIG. 94. A MODERN CAMERA.
(By courtesy of Messrs. Kodak, Ltd.)

film. The latter are coated with a special coating of chemicals which are affected by light, so that in the parts of the image that are brightest and where there is the greatest intensity of light, the greatest chemical change is produced. When the photo has been taken, further chemical changes are produced by developing and "fixing" the film; it then ceases to be affected by light, and can be placed on sensitive paper, so that photos can be printed from it.

To obtain a sharply defined image, the lens can be adjusted at various distances from the film by means of bellows. The further away the object, the nearer the image is to the lens, and so the bellows must be more closed. There is, therefore, a pointer on the side of the bellows, which moves over a horizontal scale indicating various distances of the object corresponding to certain positions of the bellows and lens (Fig. 94). The definition is still further improved by a stop placed in front of the lens; this is a metal plate with a circular hole, the size of which can be made to vary. The stop improves the definition of the image by cutting off all but the central rays; the rays passing through the edges of the lens are refracted more and come to a slightly different focus thus making the image slightly blurred. Since the stop also cuts off some of the light it must be varied according to the brightness of the day.

EXPT. 34. **Effect of the stop of a camera lens.** Cut a hole 2 inches square in a cardboard screen and fix a piece of wire gauze over it. Place a lamp behind to illuminate it. Set up a lens so that a diminished image of the gauze is obtained on a screen. Now cut holes of various sizes in pieces of black paper to act as stops to the lens. Note their effect on the brightness and definition of the image.

Until a photo is taken, the camera is in darkness and a shutter covers the lens. The timing arrangement can be set, so that this is released for $\frac{1}{50}$ or $\frac{1}{25}$ second, or any exposure suitable to the brightness of the day. Too short or too long an exposure will cause too faint or too pronounced an effect on the sensitized film.

The preliminary adjustments that must be made before a photo is taken are the setting of the bellows, the adjustment of the stop, the fixing of the time exposure and the arranging of the view by means of the view finder (generally a lens and a prism reflecting light at 90°).

The eye. The eye is a natural optical instrument similar in type to the camera. It is encased in a hard white substance

called the *sclerotic*; the front part of this, the "white of the eye", is transparent and is called the *cornea*. Light enters the eye through the *pupil*, and the *crystalline lens* (Fig. 95); the pupil acts like the stop of a camera in regulating the amount of light that passes through the lens, but its adjustment is automatic, and the pupil can be seen to get smaller or bigger in its surrounding *iris*, according to whether a bright or a dull surface is being viewed. In front of the lens there is a transparent fluid called the *aqueous humour*, and behind it in the eye itself, a transparent jelly-like substance called the *vitreous humour*.

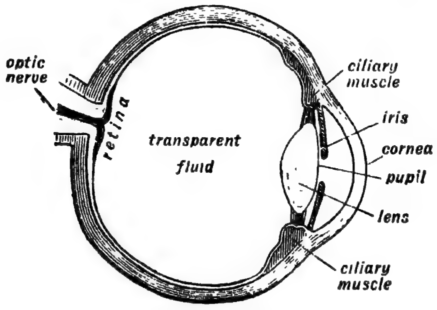


FIG. 95. HORIZONTAL SECTION THROUGH THE HUMAN EYE.

By means of the lens, images are formed on the *retina*, a sensitive network of nerves at the back of the eye. Undue brilliance of the image which might injure these nerves is prevented by the action of the pupil. The image impressions received by the retina are conveyed by the *optic nerve* to the brain. It has been seen by experiment that the real images produced must be upside-down, but the brain is accustomed to interpret the sensations received as views of upright objects. In order that objects at different distances can be seen distinctly and a well-defined image obtained on the retina, the focal length of the lens can be altered by the *ciliary muscles* contracting and making the lens thicker in the centre, thereby strengthening it. If this natural adjustment

is lacking, there is defective vision, and correction by spectacles is necessary.

The impressions made on the retina last for a small fraction of a second. This persistence of vision explains the apparent motion seen in a cinema film. Actually pictures of people in slightly different positions (Fig. 96) are thrown on the screen in rapid succession, and as the images produced on the retina

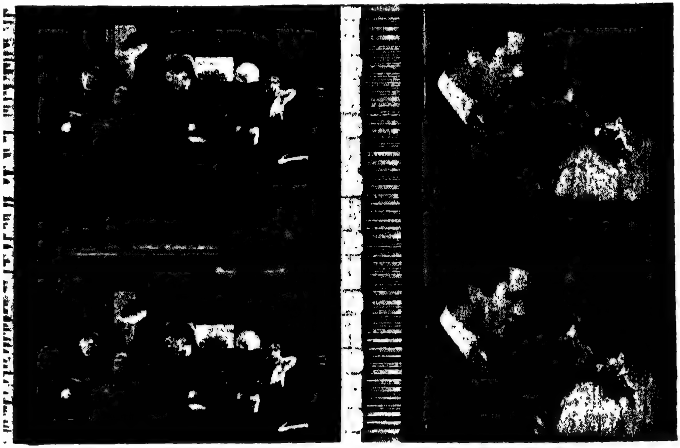


FIG. 96. PORTIONS OF TWO CINEMA FILMS, showing the forms of "sound-track" generally used: (*a*) variable area, (*b*) variable density.
(*By courtesy of the General Electric Co., Ltd.*)

persist so that they merge into one another, there is an effect of continuity of motion.

It is possible to judge distances with the eyes, because with *two eyes*, each eyeball turns so that its axis (the line joining the centre of the retina to the centre of the lens) is directed towards the object. This movement is made by muscles, and the impression of distance is gained by the strain on the muscles. If these muscles do not act normally, a person may squint. The necessity of having two eyes to judge distance can be tested by

covering one eye, and then attempting to pick up quickly an object some feet away. A further advantage of two eyes is that the solidity of the object is better realised; this can be seen by holding a book with its edge towards the eyes, and looking at it with one eye closed and then the other. The view obtained in either case is much less complete than when two eyes are used.

Spectacles. Defective sight may be due to faulty eye lenses and muscles or to eyeballs which are too long or too short. For a perfectly normal eye at rest with the ciliary muscles relaxed, parallel light should come to a focus on the retina (Fig. 97 (i)).

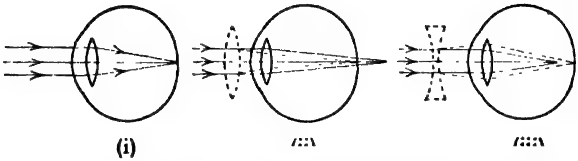


FIG. 97. IN THE NORMAL EYE (i) PARALLEL LIGHT IS FOCUSSED ON THE RETINA. IN THE LONG-SIGHTED EYE (ii) AND THE SHORT-SIGHTED EYE (iii), LENSES MUST BE USED TO AID THE EYE-LENS.

When nearer objects are in the field of view, the lens is made stronger by the ciliary muscles, so that images, instead of falling behind the retina, are focussed on it; the limit to which this adjustment can be made is the *near point* of distant vision and is 25 cm. A normal eye has, therefore, the power of accommodation to view things from great distances up to 25 cm., but with old age this power diminishes.

In **long sight** or **Hypermetropia**, the lens is too weak, or the eyeball too short for parallel light to be focussed on the retina (Fig. 97 (ii)). The ciliary muscles can act and correct this defect, but since they have begun to act when they should be at rest, they reach their limit sooner, and the near point of such eyes is too great; consequently a long-sighted person holds a book some distance away to see it distinctly. To correct the defect, a converging lens is used to make the rays converge more quickly.

In **short-sight** or **Myopia,** the lens is too strong, or the eyeball too long. In this case, parallel light is focussed in front of the retina (Fig. 97 (iii)) and a blurred image is seen. The ciliary muscles cannot weaken the eye lens and correct the defect, and so there is a limiting distance at which objects can be seen, the *far point* of vision. Spectacles consisting of *diverging* lenses must be worn for viewing long distances ; they make the rays diverge to form an image on the retina.

Colour. When the light waves fall on the nerves of the retina, they produce a sensation of colour as well as of shape. White light is really a mixture of all the coloured lights, and the various wave-lengths of light waves of from 0·00004 to 0·00008 cm. as given in the table on page 84, represent light varying in colour from violet to red. It has been seen that a prism affects the colour of light, and Sir Isaac Newton first obtained coloured light from a beam of sunlight by passing it through a prism.

The spectrum. By means of a prism, light of various wavelengths can be separated ; and this process of **dispersion** produces the bands of coloured light that form a **spectrum** (Fig. 98).

A good spectrum may be obtained with an optical lantern. A narrow slit is cut in a piece of cardboard and when this is placed in the slide-carrier of the lantern, a sharp image of the slit can be focussed on a white screen. A prism is then placed in the path of the beam, and its position and that of the screen adjusted so that a pure spectrum is obtained. This consists of successive images of the slit in the colours red, orange, yellow, blue, green, indigo, violet, the red being the least deviated from the original direction of the light and the violet most. If a piece of bright red ribbon is passed through the different colours, it appears red in the red light, but black in all the other colours. Similarly green ribbon appears green in green light, but black in other parts of the spectrum. White appears to be the same colour as the light in which it is placed, while black remains black throughout.

If pieces of red and blue glass are used to intercept the light, parts of the spectrum are cut off and only the red part or the blue part remains. If a second prism is placed parallel to the first, but with its base in the opposite direction, the coloured light can be recombined to form white light; the effect is that of a parallel-sided glass slab, so that the white image of the slit reappears slightly displaced in position.

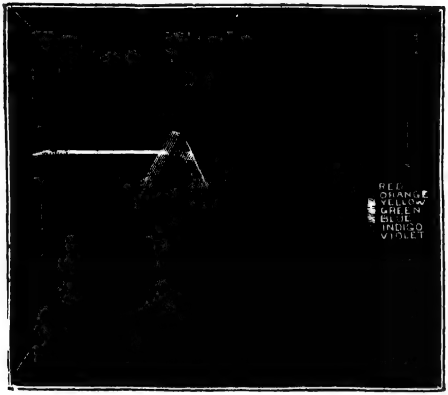


FIG. 98. REFRACTION AND DISPERSION OF WHITE LIGHT BY A PRISM.

Colours of opaque and transparent bodies. It has been seen that things are only visible because light from them is reflected to the eyes. But all the white light falling on a body is not reflected; some is absorbed and, if the substance is transparent, much is transmitted. A green leaf appears green, because it reflects the green light falling on it, and absorbs the rest of the white light, just as green ribbon reflected the green light of the spectrum, but appeared black in all the other colours. Coal is black in any light because it absorbs practically all the light falling on it. A red rose reflects red light, but a white one reflects all the colours equally, and this mixture on reaching the eye gives the impression of white.

A transparent substance like red glass transmits red light, but absorbs other colours, so that only the red part of the spectrum passes through it. If surrounding things are viewed through it, they appear red if any red light is reflected from them which can pass through the glass ; otherwise they look black. Transparent substances like water and glass transmit all the colours of the spectrum equally.

Colours by artificial light. If a new dress is bought by artificial light, and if fabrics are chosen by gas or electric light, they will appear different when viewed in the daylight ; a blue dress may look surprisingly bright, and pinkish mauve curtains may seem to have a bluer hue. The reason for this is that the spectrum of electric or gas light contains a greater proportion of red than daylight and a less proportion of blue. So a blue dress looks duller by electric light, because there is less blue to be reflected in the light falling on it, than there is in daylight, and mauve curtains find more red to reflect in the electric light and more blue in the daylight.

Most shops nowadays use fluorescent tubes which contain fluorescent powders excited by a mercury vapour discharge. There are types known as "Daylight", "Natural", or "Colour-Matching", the latter kind being specially designed to give an accurate effect of north sky daylight.

Often on the stage of a theatre, changes in the colours of the dresses may be observed when limelight of different colours is thrown on the performers. So an actress in a blue dress appears to be in black if she moves into a beam of red limelight.

Colour effects in nature. The blue of the sky, the red of the sunset, the pink glow of snow at sunset, are all due to the reflection of the sun's rays by the particles of dust and moisture in the atmosphere. Such particles cannot reflect waves of greater wave-length than their own size, so the longer wavelengths of red and yellow can pass through them, while the shorter blue waves are reflected and scattered. It is these

scattered blue rays that are seen on looking up at the sky in the daytime. At sunset, the sunlight has to pass through a greater thickness of air, and only the red and yellow penetrate through. A similar effect is seen when the sun appears red through a mist.

FIG. 99. A VIEW OF THE ISLE OF MAN.

Taken from Cumberland by a staff photographer of "The Times" using an Ilford infra-red plate and filter and a long-focus lens. The peaks shown are over forty miles away.

(*By courtesy of "The Times"*)

In the recent development of infra-red photography, use is made of the greater penetrating power of red and infra-red rays. In the usual form of photography, the rays affecting the sensitive plate are the ultra-violet ones, but if these are filtered out, and a plate sensitive to red rays is used, a photograph can

be taken of views a great distance away even if mist intervenes (Fig. 99).

A rainbow is produced by the reflection, refraction and dispersion of light by raindrops. An observer must have a shower of rain in front of him and the sun above and behind him. The light entering a raindrop is refracted and as the refraction is

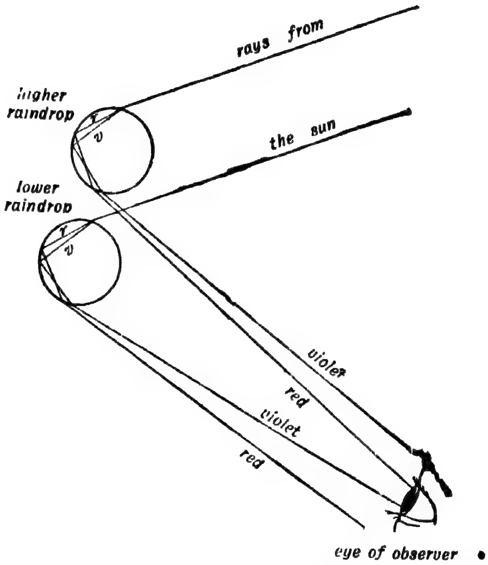


FIG. 100. THE ACTION OF RAINDROPS IN FORMING A RAINBOW.

unequal, dispersion also occurs. At the back of the drop reflection takes place (Fig. 100) and on emerging the light is still further dispersed. The reflection reverses the order of the colours, so that red is seen on the outside. In a double or secondary rainbow, the violet part is seen on the outside and the red inside. A rainbow appears curved in shape because all the drops which can produce an effect on the observer are situated along the arcs of circles.

CHAPTER VIII

MAGNETS. MAGNETIC FIELDS. MAGNETIC EFFECT OF ELECTRIC CURRENT. MEASUREMENT OF CURRENT. ELECTRIC MOTOR. OHM'S LAW. PRODUCTION OF CURRENT

Lodestone. At Magnesia in Asia Minor, large quantities of an ore called magnetite are to be found. This ore has two special properties; (1) if suspended so that it can turn freely, it always settles in a definite direction and (2) it attracts iron filings and small pieces of iron and steel (Fig. 101). As early as 2000 B.C. the Chinese seem to have been aware of the curious properties of this substance, and in quite early times, it was used for steering ships, so that it came to be given the name of lodestone or " leading-stone ".

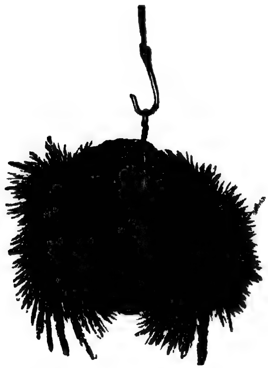


FIG. 101. LODESTONE ATTRACTS IRON FILINGS, AND, IF FREE TO TURN, SETTLES IN A DEFINITE DIRECTION.

Magnets. The magnetic properties of lodestone can be imparted to pieces of steel. Hence artificial magnets of this kind, when freely suspended, settle in a definite direction—north-south—and the end pointing north is called the north-seeking pole (marked N on the magnet), while the other is the south-seeking or S pole.

EXPT. 35. **Simple law of magnetism.** Take a steel needle and magnetise it by stroking it with one end of a bar-magnet, taking care always to stroke it in the same direction. To test if the needle

is magnetised, dip it into iron filings, and see if they adhere to the ends in tufts. Wipe off the filings and suspend the needle in a paper stirrup by a thread of unspun silk fibre. Let it settle in a definite direction and mark the end that points north.

Now bring up the N. pole of a bar-magnet to the marked end of the needle ; the latter should be repelled and move away. Repeat with the S. pole of the magnet ; there should now be an attraction. See also what happens at the unmarked end of the needle when the two poles of the bar-magnet are brought up to it.

The simple law of magnetism is that **like poles repel one another and unlike poles attract one another.**

Magnetic induction. There is attraction between the unlike poles of magnets but also *unmagnetised* pieces of iron and steel (like iron filings and pen nibs) may be attracted by a magnet. This is because a magnetic pole *induces* a pole of an opposite kind in the unmagnetised metal near it and so attraction occurs. This may be shown by supporting a bar of unmagnetised iron near a strong bar-magnet (Fig. 102) and showing by

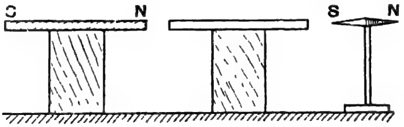


FIG. 102. THE BAR OF UNMAGNETISED IRON BECOMES MAGNETISED BY INDUCTION.

a compass needle that unlike and like poles are induced in the near and far ends respectively of the unmagnetised rod. Even a tiny iron filing has magnetism induced in it in this way.

Attraction is therefore no sure test of whether a piece of metal is magnetised or not, because the attraction may be due either to an unlike pole or to induction in unmagnetised iron or steel. A repulsion, on the other hand, is a certain indication of opposite polarity.

Theory of magnetism. The reason that artificial magnets can be made of iron or steel is that minute particles of these substances seem to act like tiny magnets and turn under the

influence of the magnetising force. This may be illustrated by drawing the pole of a magnet along a glass tube containing steel filings (Fig. 103 (i)). They turn and settle in an orderly fashion and, if the N. pole is drawn several times in the direction shown, it would be expected that the right-hand end of the tube would have S. polarity owing to the S. poles induced in the attracted steel filings at the end. Except at the ends, the north and south poles of the various filings would neutralise one another (Fig. 103 (ii)). The *steel* filings retain their orderly arrangement until the tube is shaken up, but if *iron* filings be used, they become disorderly directly the magnetising force is removed.

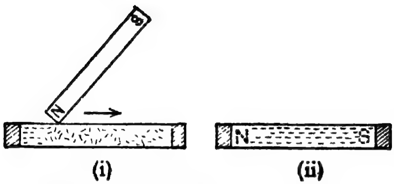


FIG. 103. THE STEEL FILINGS SETTLE DOWN IN AN ORDERLY FASHION WHEN MAGNETISED.

Solid steel and iron have the same characteristics as the filings. Thus permanent magnets (like the compass) must be made of steel, while for the temporary magnetisation required in electric bells, telephones, magnetos etc. iron is used.

Compass. A **compass** contains a magnetised needle of hard steel supported or suspended so that it can turn freely. The needle settles in a definite direction, because the earth acts as if it were a magnet, and the poles of the needle are attracted by the **north and south magnetic poles** of the earth. These poles are not identical with the geographic ones, the north magnetic pole being situated at Boothia Felix in North America and the south magnetic pole in South Victoria Land. Consequently a magnetised needle settles in the direction of the **magnetic meridian** and not along the geographic meridian. (It was seen in Chapter I that the meridian of an observer is the plane passing through him and the north and south poles of the earth.) The directions indicated by a magnetised needle must therefore be corrected to geographic directions by means

of charts which are issued by the Admiralty, and ships and aeroplanes use such corrections when estimating their course from compass readings.

Fig. 104 shows an ordinary **pocket compass** that can be used when walking across country. The compass is held horizontally and turned until the N.-S. line of the card is directly under the needle (the magnetised needle always points N.-S.); the other points of the card then point in the right direction.

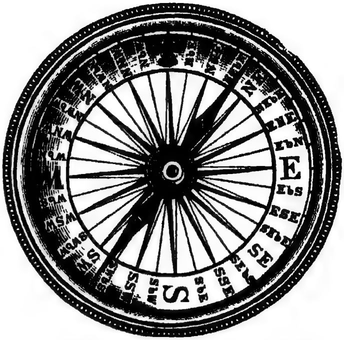


Fig. 104. A Pocket-Compass.

For steering ships and aeroplanes, either a liquid compass or a gyrocompass is generally used. Fig. 105 shows a **Chetwynd liquid compass** in which the magnet and card are supported on a hollow float in a mixture of alcohol and water. Since the magnet and card are fixed together, the whole card rotates to

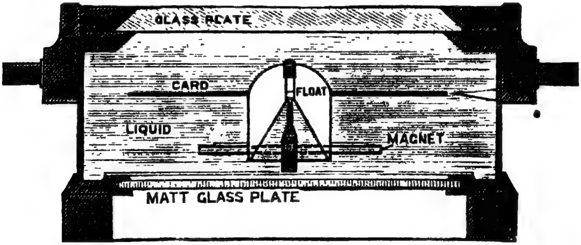
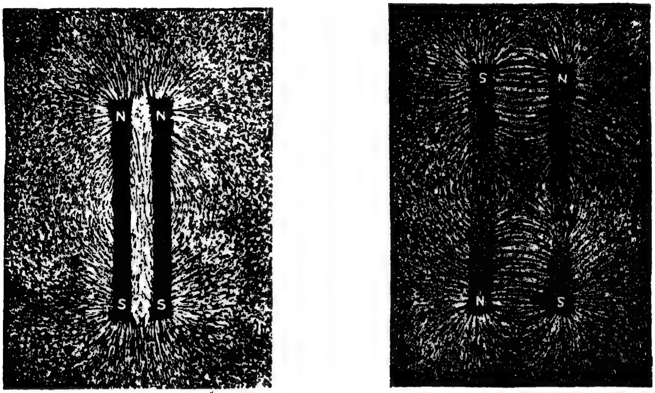


Fig. 105. A Chetwynd Liquid Compass.

indicate the directions of the points of the compass. The advantage of such a compass is that it remains steady when tilted, and it can be illuminated at night by lamps placed below. The **gyro-compass** is particularly useful on ships like submarines, where the excessive amount of iron would prevent an ordinary magnetic compass working. A heavy wheel is made to rotate

rapidly by means of an electric motor and under the effects of its own inertia and the revolution of the earth, the axis of the gyro is swung into the same plane as the axis of the earth.

Magnetic field. Iron filings are affected by a magnet even when they are a short distance away from it ; the space all round the magnet in which the magnetic force acts is called the **magnetic field** of the magnet. In the various parts of the field, the *direction* of the force varies and lines showing this direction



(i) (ii)

FIG. 106. MAGNETIC FIELDS SHOWN BY IRON FILINGS.

are called **lines of force.** Such lines may be mapped out either with a small compass needle or by iron filings. The latter settle in definite directions because they become magnetised by induction.

EXPT. 36. **Mapping magnetic fields with iron filings.** Place a sheet of stiff drawing-paper over a bar-magnet supporting it in a flat position by rulers at the edges. Take a muslin bag containing iron filings and shake the filings out so that they are scattered uniformly over the paper. Tap the paper gently to make them settle.

Repeat with two magnets placed (1) with like poles side by side, (2) with unlike poles together. Fig. 106 shows the results obtained.

Magnetic effect of an electric current. It will be seen later in the chapter that an electric current can be supplied by a voltaic cell or by the dynamos of a generating station. When a current flows through a solenoid (that is, a long uniform coil in which the wire lies in the surface of a cylinder), a magnetic field similar to that of a bar-magnet is produced, and a piece of steel placed inside the solenoid can be made into a permanent magnet, or a piece of iron into a temporary magnet.

Electromagnet. When a piece of soft iron is placed inside a solenoid, a very strong magnet is produced so long as the current flows, but the magnetic properties vanish immediately the current ceases.

EXPT. 37. **Magnetic properties of soft iron.** Take a piece of glass-tubing 6 inches long, and $\frac{3}{8}$ of an inch in diameter. Wind closely a coil of cotton covered copper wire on it and so make a solenoid. Connect the ends of the wire to the terminals of a Leclanché cell with binding screws. Place a piece of soft iron or a number of strands of soft iron wire inside the tube, so that the ends project beyond it. Support the tube on a block of wood, and bring a small pair of scissors and some pen-nibs up to the iron. Notice that they are attracted and will hang suspended from the iron while the current is flowing, but drop off immediately the wire is disconnected from the cell. Start the current again, and find which is the N. end of the electromagnet by bringing up a compass needle, and seeing at which end the N. end of the compass is repelled. Notice the direction in which the current flows round the solenoid assuming it flows from the carbon terminal of the cell to the zinc one.

Such an arrangement is an **electromagnet** and its magnetic force is much greater than that of the solenoid of wire alone. The polarity of the electromagnet can be found by the simple rule that *if the fingers of the right hand bend round in the direction of flow of the current, the outstretched thumb points toward the N. pole* (Fig. 107). Often the iron core is bent round into a horseshoe, and the wire must then be wound in opposite directions on

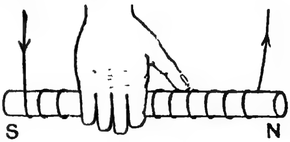


FIG. 107. THE POLARITY OF AN ELECTROMAGNET.

the two limbs, so that the ends are of opposite polarity. If a strong current and many turns of wire are used, a very powerful electromagnet can be made ; Fig. 108 shows one used for lifting large quantities of pig-iron.

FIG. 108. WITTON-KRAMER CIRCULAR LIFTING MAGNET.
(*By courtesy of Witton-Kramer Works*)

Electric bell. An electric bell (Fig. 109) consists of a small electromagnet together with a movable armature SA, supported on a spring S, and carrying a hammer H. From the terminals T and T′ wires pass to the bell-push and to a Leclanché cell.

An electric current can only flow if it has a path consisting of a complete circuit of conducting material. When the bell-push is pressed the circuit is completed and a current flows from the

cell. The electromagnet acts and attracts the armature, but the armature then ceases to be in contact with the screw at C and the circuit is broken. The current stops, the electromagnet loses its magnetic properties, and the armature being no longer attracted, springs back so that there is contact at the screw once more. The circuit is then complete again, the current flows and the whole process is repeated. Every time the armature moves forward the hammer strikes the bell, and

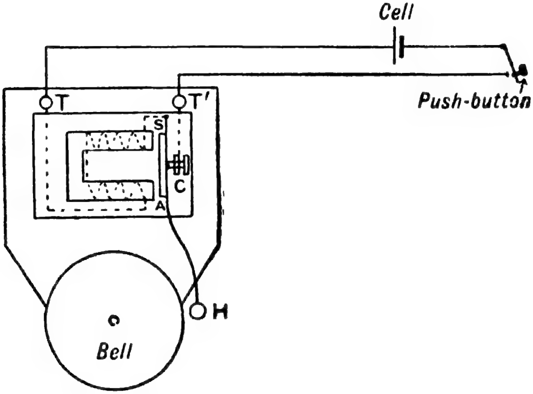


FIG. 109. ELECTRIC BELL CIRCUIT.

as the " makes " and " breaks " of the circuit occur in rapid succession, the continual hammerings on the bell keep it ringing for as long as the bell-push is pressed.

Telephone. The action of a telephone receiver is somewhat similar. Instead of an armature, a thin circular iron diaphragm vibrates to and fro under the influence of an electromagnet (Fig. 110). A permanent magnet exerts a constant attraction on the diaphragm, and in addition the electromagnet exerts a varying attraction because its strength varies when the current flowing in its coils fluctuates. These fluctuations are caused at the transmitter by the sound waves, and since the vibrations of the iron diaphragm of the receiver correspond to them,

similar sound waves are reproduced at the receiving end by the vibrating diaphragm.

The **transmitter** or microphone has a carbon diaphragm which is in contact with carbon granules (Fig. 110). The sound waves falling on the diaphragm make it vibrate, so that the pressure it exerts on the granules varies. The resistance to the current flowing through the transmitter thus continually

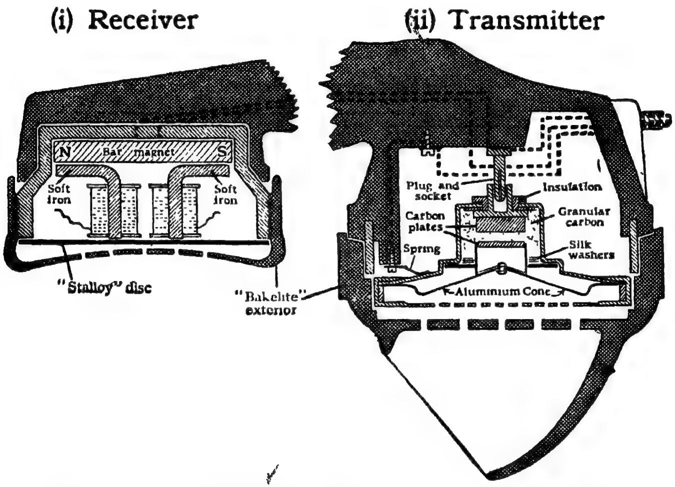


FIG. 110. A TELEPHONE RECEIVER AND TRANSMITTER.

changes and fluctuations of the current are produced, which travel along the telephone wires to the receiver.

Use of magnetic effect for measuring current. The magnetic effect produced when a current flows along a wire can also be used as a means of detecting and measuring current.

EXPT. 38. **Deflection of a compass needle by a current.** (*a*) Stretch a long piece of covered copper wire along the magnetic meridian. Support a compass needle above the wire and let it come to rest in the meridian parallel to the wire. Now connect the ends of the wire to a dry cell, so that a current flows from north to south (remembering, as in the previous experiment, that the current is

considered to flow from the carbon terminal of the cell). Note the direction of deflection of the N. pole of the needle. Repeat with the needle in position below the wire. Reverse the connections between the wire and the cell, so that the current flows from south to north, and repeat the observations.

Tabulate results thus :

Direction of current	Position of compass needle	Direction of deflection of N. pole of needle
North to South.	Above wire.	West.
North to South.	Below ,,	East.
South to North.	Above ,,	East.
South to North.	Below ,,	West.

(*b*) Next support the compass horizontally on a piece of cardboard and arrange a loop of wire round it, so that needle and loop lie in the plane of the meridian. Connect the wire to a cell and note the deflection of the needle. Now coil several more loops of wire round the needle and again observe the deflection.

The right-hand rule given on page 121 can be applied to this experiment. In part (*a*), if the fingers of the right-hand point in the direction of the current and the *palm* of the hand *faces* the compass, the outstretched thumb will indicate the direction in which the north pole tends to move. Similarly in part (*b*) the outstretched thumb shows the direction of deflection of the N. pole of the needle. This latter arrangement illustrates how the magnetic effect of a current is used in the construction of galvanometers.

Galvanometers. A galvanometer is an instrument for measuring the strength of an electric current. A very simple galvanometer can be made from 20 or 30 coils of wire placed round a magnet to which a light pointer is attached (Fig. 111). To use the instrument it is turned until the magnet and coils lie in the meridian. When currents of different strengths pass through the coils, the magnet is deflected to different extents and the light pointer attached to it moves across the scale. If

certain facts are known about the instrument, the strength of any particular current can be calculated from the scale reading.

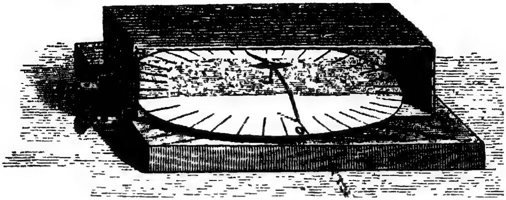


FIG. 111. A SIMPLE GALVANOMETER.

The unit used to measure current is the **ampere**, and the number of amperes flowing through a circuit is a measure of the quantity of electricity flowing through it per second. In a similar way, we might measure the size of a stream by finding what quantity of water flowed past a certain spot in a second. The unit in which quantity of electricity is measured is the **coulomb**, and if the rate of supply is one coulomb per second, the size of the current is one **ampere.**

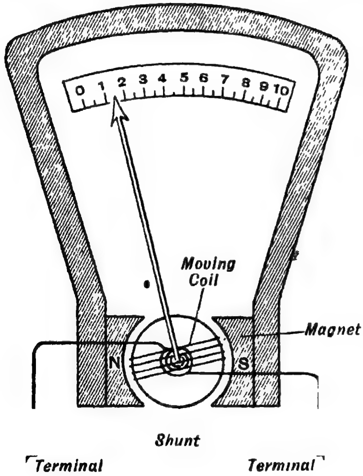


FIG. 112. THE CONSTRUCTION OF AN AMMETER.

Ammeters. Instead of a moving magnet inside a stationary coil, many galvanometers have a movable coil suspended between the poles of a stationary magnet. The coil is deflected when a current flows through it to an extent depending on the strength of the current. An **ammeter** is a moving coil galvanometer of this type, constructed so that when the pointer attached to the coil moves, the readings on the scale show the strength of the current directly in amperes (Fig. 112).

The wire called the shunt is placed across the terminals, so that only a small proportion of the actual current passes through the coil.

Electric motor. An electric motor works in a similar way to an ammeter. A current flows through coils of copper wire called an **armature,** the armature being placed between the N. and S. poles of a permanent magnet. The armature rotates

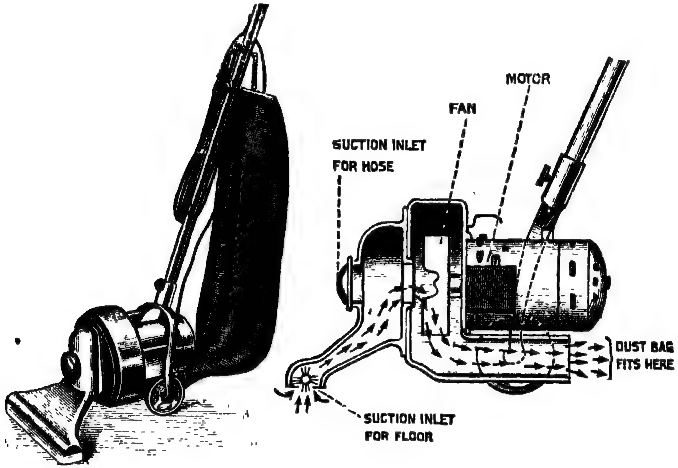


FIG. 113. AN ELECTRIC VACUUM CLEANER.
(By courtesy of the Edison-Swan Electric Co., Ltd.)

when the current flows and this motion may be transmitted to an electric fan or to drive a sewing machine or a cake-mixer. A vacuum cleaner (Fig. 113) contains a fan driven by a small motor, the electric current for which is obtained from the ordinary mains. The rapid rotation of the fan sets up a partial vacuum, and the pressure of the atmosphere forces air into the partial vacuum together with dust and dirt; the dust is then passed into a cloth bag.

Supply of electricity. It has already been mentioned that the sources of supply of electricity are (1) a voltaic cell, (2) the

mains supply from the dynamos of a generating station. The difference between the two is one of electric pressure.

The characteristics of a current of electricity can best be understood by comparison with a current of water. In order that a stream of water may flow, there must be pressure due to a difference of level, as, for example, in a waterfall. The greater the difference of level (or the higher the waterfall), the greater the pressure forcing the water along its path. The greater the quantity of water supplied in a given time, the greater the size and width of the stream. It was seen on page 126 that in the case of a current of electricity, the quantity of electricity is measured in coulombs, and the size of the current in amperes. The electric pressure (or **voltage**) forcing the current to flow is measured in **volts.**

The essential difference between the two sources of supply of electricity is that whereas the electric pressure (or **electro-motive force**) of a cell is only one or two volts, that of house mains is being standardised by the Grid scheme of the Central Electricity Board at 230 volts. Thus a cell may be used for small installations like electric bells or telephones, but for all large installations for heating, lighting, transport and electro-plating, the mains are needed.

Ohm's Law. In considering the current produced in a wire by a given electric pressure, one further thing must be allowed for, that is, the **resistance** that the current encounters as it flows through any given conductor, The resistance varies with the material and although all metals are **good conductors** of electricity, silver is the best and copper the next best conductor. Silver is an expensive substance for common use ; consequently the wires for all electrical connections are made of copper. Other kinds of wire are used in circuits when it is necessary to introduce more resistance; this fact will be discussed more fully in the next chapter in connection with heating appliances. Some substances have such a high resistance that they do not conduct electricity appreciably ; they are said to be **insulators.**

Thus rubber, a good insulator, is used for coating the copper wires conveying current in a house. Porcelain, wax, mica, ebonite are all good insulators. An insulator can stop the passage of a current of electricity because a current can only flow if it has a path consisting of a complete circuit of conducting material.

The unit in which resistance is measured is the **ohm**, and there is a simple relation between the electromotive force (in volts), the current (in amperes) and the resistance (in ohms) for any given circuit. This is known as **Ohm's Law**, which states that :

$$\textbf{Current} = \frac{\textbf{electromotive force}}{\textbf{resistance}},$$

or

$$\textbf{amperes} = \frac{\textbf{volts}}{\textbf{ohms}}$$

If two of these quantities are known the third can be calculated. The current in a circuit can always be measured with an ammeter, and the voltage with a **voltmeter**, an instrument similar in construction to an ammeter but having a high resistance connected to the moving coil ; the readings on the scale give a measure of the electric pressure. An experiment depending on Ohm's Law and making use of these instruments will be described in the next chapter.

Production of current by cells. It has been seen that an electromotive force of a few volts can be obtained with a voltaic cell. The Leclanché cell (or its modification, the dry cell) is used for electric bells, telephones, telegraphs and pocket flash lamps.

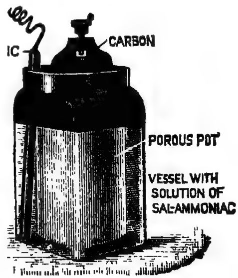


FIG. 114. A LECLANCHÉ CELL.

It consists of a glass vessel (Fig. 114) containing a strong solution of sal-ammoniac in which is placed a porous earthenware pot containing small pieces of carbon and black oxide of manganese and a carbon plate. The carbon plate and a

zinc rod in the outer vessel form the two terminals of the cell to which connections are made. When the cell is in use, chemical action takes place between the sal-ammoniac and the zinc so that gases are evolved. The function of the black oxide of manganese is to remove the gas, but since it only effects this slowly, continuous use of the cell results in an accumulation of gases. This reduces the current the cell can supply, but if it is given a short rest, the gas is removed, and the cell recovers. It follows, therefore that it is most suitable for use with electric bells and telephones where a current is only required for short periods at a time. It requires little attention except more water or a fresh supply of sal-ammoniac when the solution evaporates.

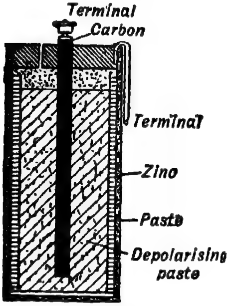


FIG. 115. A DRY CELL.

The dry cell (Fig. 115) is a convenient modification of the Leclanché in a compact and portable form. A small type is used for pocket flash-lamps while a larger kind is used for telephones. Instead of the sal-ammoniac solution, there is a paste of plaster of Paris, sal-ammoniac and zinc chloride, and the zinc rod is replaced by a layer of sheet zinc, which serves as a containing vessel.

EXPT. 39. **Construction of a dry cell.** Take a disused pocket lamp battery and remove the paper and cardboard covering. Notice how the zinc cylinders are connected one to another, the zinc to the adjacent carbon rod, etc. Cut across one zinc cylinder, and note the central carbon rod surrounded by a black mixture, and the white paste outside.

The accumulator. Accumulators are used for the "self-starter" and lighting of motor-cars, for certain types of wireless sets and for vehicles such as dust carts and delivery vans. They are also valuable for storing electricity for lighting, particularly in private house plants, or in hospitals, where a reserve supply is essential.

An accumulator consists of a number of specially prepared lead plates, packed closely together, alternate plates being connected to one of two lead strips (Fig. 116) which go to the terminals of the cells. These plates are immersed in dilute sulphuric acid the specific gravity of which should not exceed 1·21 or fall below 1·15.

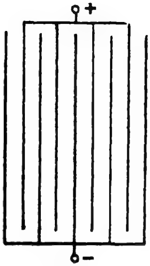


Fig. 116. Arrangement of Plates in an Accumulator.

In order that an accumulator may be used as a source of electricity, it has first to be charged by sending through it a current from the mains. This causes chemical changes to take place in the plates, and in this way electrical energy is converted into chemical energy. The chemical energy so stored can be reconverted into electrical energy by taking a current from the cell; this latter current flows in the opposite direction from the charging one. In this way the cell gradually becomes discharged; its voltage falls from about 2·2 volts to 1·8 volts and the specific gravity of the sulphuric acid to 1·15. The voltage and specific gravity should not be allowed to fall below these values without recharging the cell, or it becomes permanently injured.

Induced currents. It has been seen that a current has a magnetic effect but conversely a magnetic effect can produce a current. This fact was discovered by **Michael Faraday** (1791-1867) and the continual growth in the use of electricity for everyday purposes is the outcome of his brilliant researches. Faraday realised that if magnetic lines of force move across a conductor an electromotive force is produced in the conductor.

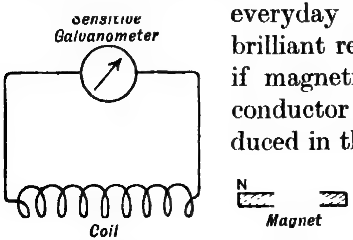


Fig. 117. Current induced by a Moving Magnet.

Expt. 40. **Induced currents.** Obtain a coil of 50 turns of wire and connect it to a sensitive galvanometer. Take a bar-magnet and

push the N. pole into the coil (Fig. 117). Notice the sudden deflection of the galvanometer needle. *Observe also that when the magnet is stationary, there is no deflection of the galvanometer.* Now withdraw the magnet and notice the deflection is in the opposite direction. Repeat, bring the S. pole of the magnet up to the coil first.

Repeat again, keeping the magnet fixed and pushing the coil on to the magnet.

The similar results in both parts of the experiment show that it is the relative *motion* of the coil and the magnetic field which produces the induced currents. It is on this principle that dynamos for producing electricity on a large scale are constructed. It was seen earlier in the chapter that in an **electric motor :**

$$\left.\begin{array}{l}\text{Magnetic field}\\ \text{Current}\end{array}\right\}\text{produce motion.}$$

Now similarly for a **dynamo :**

$$\left.\begin{array}{l}\text{Magnetic field}\\ \text{Motion}\end{array}\right\}\text{produce current.}$$

The dynamo. In a dynamo, a coil is made to rotate between the poles of a powerful magnet, and as the coil cuts across the magnetic lines of force continually, an induced current is set up in it.

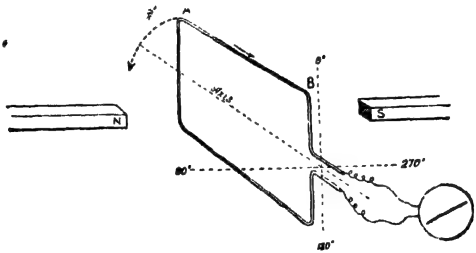


FIG. 118. THE PRINCIPLE OF A DYNAMO.

EXPT. 41. **Principle of the dynamo.** Set up a coil (Fig. 118) between two bar-magnets supported on blocks of wood. Connect the coil to the terminals of a sensitive galvanometer. Start with the coil in a vertical position and turn it quickly through 180°, noticing the

deflection of the galvanometer that is produced. Turn the coil quickly through a further 180° and observe that the deflection is in the opposite direction.

The experiment shows that as the coil rotates, currents are formed first in one direction, then in the other. These are called **alternating currents** and if the ends of the rotating coil of the dynamo are connected to rings with which they make continuous sliding contact, the current collected by the brushes [B_1 and B_2 in Fig. 119] is an alternating one, and the machine is an **alternating current dynamo.** It is possible however, to join the ends of the rotating coil to a **split-ring** or **commutator** so that the collecting brushes make contact alternately with the two semicircles and current always passes in the same

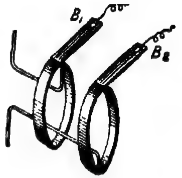


FIG. 119. COLLECTING BRUSHES OF AN ALTERNATOR.

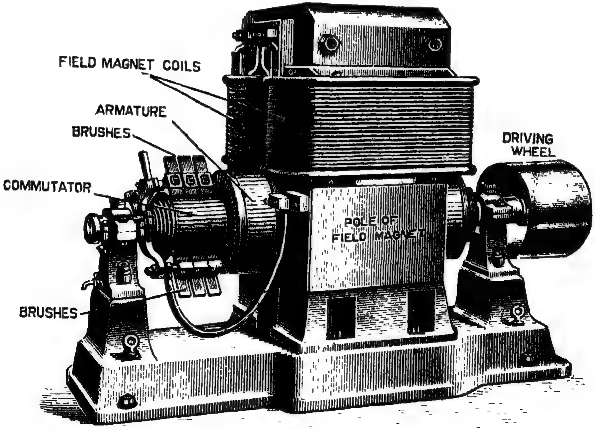


FIG. 120. A DYNAMO.

direction to the external circuit through the same brush: the current is then direct and the machine is a **direct current dynamo.**

A real dynamo is of course much more complicated than the simple one described above. The permanent stationary magnet is a powerful electro-magnet, and the rotating coil consists of an **armature** with a soft iron core and a number of distinct windings of wire each connected to a metallic segment forming part of a more complicated commutator (Fig. 120). To rotate the armature between the poles of the magnet and to generate the current, steam, gas or oil engines are generally used, but in countries like Norway or Switzerland where mountain streams or waterfalls give power for water turbines, the latter are used to drive dynamos. Similar hydro-electric plants on a large scale have been established at Lochaber and Kinlochleven by the British Aluminium Company.

An electric motor and a dynamo are similar in construction and if a current be passed through a dynamo, it may be used as a motor.

CHAPTER IX

ELECTRIC POWER. HEATING EFFECT OF CURRENT. DOMESTIC APPLIANCES. HOUSE SUPPLY. LAMPS. ELECTRIC FURNACE. CHEMICAL EFFECT OF CURRENT.

Electric power. It was seen in Chapter II that energy can exist in a variety of forms and may change from one form to another. Thus the electric energy produced by a dynamo passing as a current along the mains may be converted into the heat energy of an electric fire or the energy of motion of an electric motor or the chemical energy stored in an accumulator.

When there is mechanical friction, energy is lost and may reappear as heat; similarly in the case of electricity, energy has to be expended and work done in forcing the current along a wire against a resistance; the energy lost may reappear as heat or some other form of energy. Thus it is necessary to supply energy in an electric circuit for work to be done, and the rate at which electrical energy is received at any point in a circuit is given by the product of the voltage and the size of the current. This is equivalent to the **power** or rate of doing work in the circuit, a quantity measured in units called **watts**. Thus:

$$\text{Watts} = \text{amperes} \times \text{volts}.$$

For example, an electric iron constructed for use on a 230 volt and having a current passing through it of 1·5 amperes uses power equal to $(230 \times 1{\cdot}5) = 345$ watts.

Electricity is charged for, according to the power used, but the watt is an inconveniently small unit. Thus if 1000 watts

are supplied for 1 hour, the amount of power used is **1 kilowatt-hour** or **1 Board of Trade unit.** The number of these units used is recorded on the dials of the meter. In Fig. 121, reading from left to right, the total number of units registered is 3864·2 units.

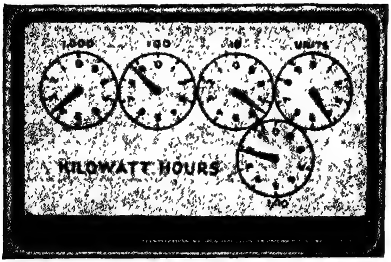


FIG. 121. AN ELECTRIC METER.
The reading is 3864.2 units.

Heating effect of current. The heat that appears when a current flows along a wire is due to the electric energy lost in overcoming the resistance of the wire. The total amount of heat evolved depends also on the strength of the current and on the time for which it flows.

The resistance of a wire depends on its thickness, its length and the material of which it is made. Hence in the construction of the various appliances depending on heat being generated, nichrome wires are chosen of a length and thickness such that they will be heated to a dull red heat, when the appliance is used on the voltage for which it is designed. If it is used on a higher voltage, the heating produced may be so great that the wires will burn out; if on a lower, the heating will be insufficient. For example, an electric iron designed for a 230 volt circuit would only become warm if used on a 100 volt circuit.

The heating effect of a small electric fire depends on the resistance of the nichrome wire used in its construction. To find the value of this resistance, a simple experiment making use of Ohm's law may be done. At the same time the power used by the radiator can be calculated.

EXPT. 42. **Resistance of an electric radiator and power used by it.** (This experiment is better demonstrated by an experienced teacher.) Connect up a circuit consisting of two main supply wires, a switch, an electric fire, an ammeter and voltmeter, making the connections as shown in Fig. 122. Notice the ammeter is connected so that the current flowing through the radiator also flows through the ammeter, while the voltmeter is connected so that its two terminals are joined to those of the radiator. The ammeter is said to be "in series" with the circuit and the voltmeter "in

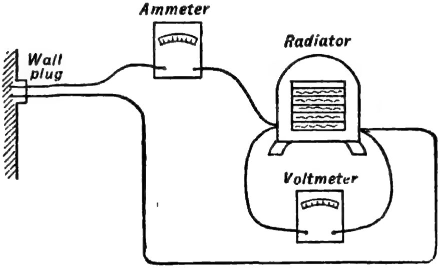


FIG. 122. EXPERIMENT TO FIND THE RESISTANCE OF AN ELECTRIC RADIATOR AND THE POWER USED BY IT.

parallel". These two instruments are always connected in this way.

Now switch on the current and read the ammeter and the voltmeter. To calculate the resistance of the radiator, it is known from Ohm's Law that:

$$\text{Current} = \frac{\text{electromotive force or voltage}}{\text{resistance}}$$

or

$$\text{Resistance (in ohms)} = \frac{\text{volts}}{\text{amperes}}.$$

Hence *divide* the voltmeter reading by the ammeter reading, and so obtain the value of the resistance in ohms.

To estimate the power used by the radiator *multiply* the voltmeter reading by the ammeter one and so find the power used in watts. This value may be checked by observing that given on the maker's label.

Domestic appliances. Domestic appliances are of two types, (1) those depending on a small electric motor driven by the

FIG. 123. SOME DOMESTIC ELECTRIC APPLIANCES.

current from the mains, (2) those depending on the heating produced in a wire through which a current is passing. The electric fan, the sewing machine and the vacuum cleaner belong to the first type. Examples of the second type are many and various : electric lamps, fires, cooking stoves, irons, grillers, kettles, toasters, bath-water heaters, milk sterilizers, shaving pots, warming pads. Some of these are shown in Fig. 123 and in most cases the general construction is obvious. The heating " element " of nichrome wire is at the base of the kettle and the milk sterilizer, but the latter is so arranged that it can be heated by either one of two circuits (two wires of different resistances), one producing enough heat for boiling and the other for simmering. A warming pad or blanket has well-

insulated wires inside a padded bag or blanket. In the cooking stove, wires beneath metal plates on top take the place of gas rings and so form hot plates. Inside the oven, wires are similarly placed to the gas jets of an ordinary gas stove. There is a thermometer on the door and the temperature can be adjusted by switching the current on or off through sections of the heater. The arrangement of the heating element of an electric fire was described in Chapter V.

House supply. All such appliances depend on the supply of electricity to the house by mains coming from the dynamos of the generating station. It should be remembered that although any part of a circuit in which the current is supplied by a voltaic cell may be touched with impunity, a dangerous shock may be experienced on touching wires and metallic parts of circuits conveying current from the mains. This is because one of the mains is generally connected to earth and the earth being an excellent conductor of electricity, there is a tendency for the current to flow through the person touching the wire to complete its circuit through the earth. Since the pressure is high, the rate at which electricity would discharge in this way would be much greater and therefore more dangerous than under similar conditions with a voltaic cell supplying the electric pressure. For this reason, wires from the mains are well insulated with layers of rubber and cotton.

Fig. 124 shows how current passes into a house through a meter and main switch, and then passes to a distributing board consisting of two busbars of brass or copper to which are connected pairs of fuses through which the current passes to the various circuits in the house. Fuses are necessary because some fault in the circuit, such as a broken lamp, may make the current pass directly along the wire without encountering any appreciable resistance. The current then becomes excessively large and its heating effect may cause a fire. To avoid this, fuses consisting of lead, tin, or tinned copper wire are included in each circuit and these will melt and burn away if the current

is much greater than the normal one. The circuit is thus broken, and the current ceases before its heating effect can lead to dangerous results. The wire is enclosed in a porcelain carrier which can be detached from its base for new wire to be inserted, when

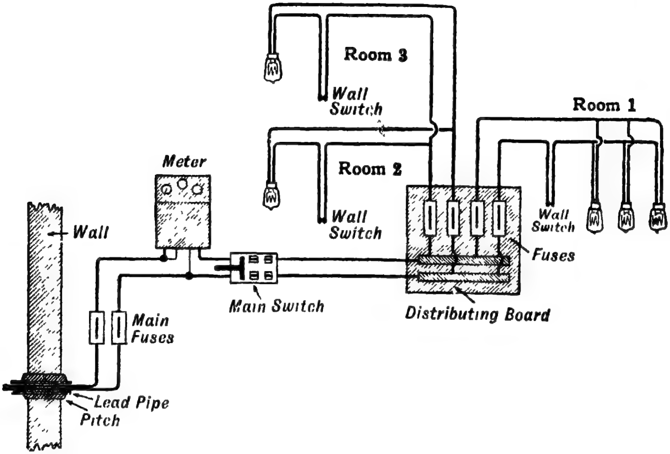


FIG. 124. THE ELECTRIC LIGHT CIRCUIT OF A HOUSE.

a fuse has burnt out. The current is always switched off at the main switch before this is done. Each circuit has a wall switch connected in series and lamps connected in parallel. This latter arrangement ensures that if one lamp in a room is faulty, the current still flows through the others.

Electric lamps. In bulb electric lamps, the source of light is a filament of fine wire which has a very high resistance, and which therefore is so much heated when a current passes through it that it becomes white-hot or incandescent. If, however, this took place in air the wire would burn away. Consequently the bulbs contain a mixture of 7% of argon and 93% of nitrogen ; these gases do not allow objects to burn in them and are known as inert gases. The light is given out by the short coiled length of the tungsten filament (Fig. 125 (i)). Since this light is concentrated over a very small area there is

a tendency for the glare to be injurious to the eyes if looked at directly. Consequently most people prefer to use lamps which have a veneer of white opal glass over the clear glass (Fig. 125 (ii)). The light from the filament is then diffused evenly over the whole bulb surface so that a soft diffused light is obtained and glare is eliminated.

Lamps are often marked with such numbers as 60W. 240V. These mean that the lamp consumes 60 watts of power and is

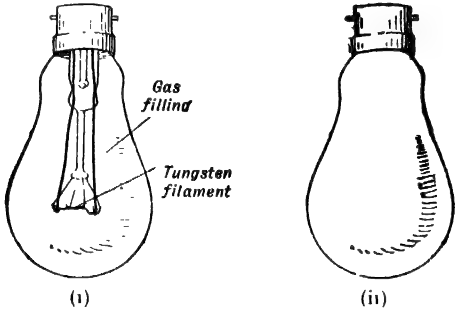


FIG 125 TYPES OF ELECTRIC LAMPS
(i) a gas-filled lamp. (ii) an opal lamp.

for use on a 240 volt circuit. The efficiency of a lamp is the power consumed for each candle power of light given so that a 60-watt lamp giving 100 candle power has an efficiency of $\frac{60}{100}$ or 0·6 watts per candlepower.

Fluorescent lighting. Fluorescent tubes are much more efficient than the ordinary bulb electric lamps just described, and they are now in common use in offices and shops and large rooms where an even diffused light is needed. Fig. 126 shows a number of these tubes varying in length from $1\frac{1}{2}$ ft. to 8 ft.

The inside of such tubes is coated with a mixture of fluorescent powders called phosphors, the type of phosphor used determining the colour of the light obtained. The gases in the tube are mercury vapour and a little argon at a very low pressure. When the electric terminals of the tube are connected to the mains voltage, there is an electric discharge

through the gases which makes the phosphors fluoresce. If certain phosphors are used an effect of daylight may be obtained, and as mentioned on page 113, "Daylight", "Natural" or "Colour-Matching" tubes are used for shop window lighting.

The power used by a lamp can be verified by an experiment precisely similar to Expt. 42.

FIG 126. FLUORESCENT TUBES OF VARIOUS LENGTHS
(By courtesy of the General Electric Co. Ltd.)

Electric furnace. The very high temperature obtainable by means of an electric current is used in electric furnaces for carrying out chemical and metallurgical processes which would otherwise be impossible. One substance that can be made in this way is "**Carborundum**", a compound of carbon and silicon, which is so extremely hard that it is used extensively for making grindstones by which knives and steel edges are sharpened. The furnace contains a mixture of coke and sand, the latter being an oxide of silicon. When a strong electric current is passed through the furnace by means of the carbon rods, the extreme heat causes chemical action between the coke and the sand, so that some of the coke combines with the oxygen of the sand, and the rest with the silicon to form carborundum.

Calcium carbide which is used for making acetylene gas for lamps like cycle lamps is a compound of calcium and carbon made in a similar way except that lime is used in the furnace instead of sand.

The composition of matter. The chemical composition of matter will be discussed more fully in Chapter XI, but to understand the chemical effect of a current, something must be known of the structure of the various substances in the world around us. Everything is made up of tiny particles called **atoms**, which are so small that even with the most powerful microscope it is impossible to see them, for they are less than a millionth of an inch in diameter. There are ninety-two different kinds of atoms occurring in Nature, and they are arranged in different ways to form all the marvellous variety of substances existing in the world, including living things and even man himself. If a substance is made up of atoms *all of one kind*, it is called an **element** and there are thus ninety-two natural elements. More will be said about the elements later, but some of the more important ones are oxygen, nitrogen, hydrogen, carbon, silicon, calcium, sodium, potassium, and iron. Several atoms either of the same or of different kinds combined together form a **molecule**, and an element is made up of molecules containing identical atoms, while a **compound** may consist of molecules similar to each other, but containing different kinds of atoms. Obviously a marvellous variety of substances is possible in this way and so the infinite variety of the world is explainable.

During the present century, scientists have been trying to discover more about the atom, and they now know that it is electrical and behaves as if it were composed of tiny particles of electricity ; these vary in number and arrangement with the different kinds of atoms. So it seems as if matter disappears and there is nothing in the world but electricity.

Chemical effect of an electric current. When certain substances are dissolved in water, the solution so formed will conduct electricity. Pure water is almost a non-conductor, but

when one of these substances is dissolved in it, it becomes conducting and is called an **electrolyte.** The reason for this is that when the substance dissolves, some of the molecules split up into parts called **ions,** which carry tiny positive or negative charges of electricity; this effect is known as *dissociation.* There are equal amounts of positive and negative charges, so the liquid as a whole remains neutral.

Now if two plates called **electrodes** are placed in the liquid so that a current can be led into it, the current may pass into the solution at the one called the **anode** and leave it at the **cathode.** When this happens, the ions in the solution begin to migrate. It will be seen in Chapter X that electric charges of an opposite kind are attracted to one another; thus the negative ions migrate to the positive plate (or anode) and the positive ions to the negative plate (or cathode), and more ions form so that the process continues. This movement of ions causes chemical changes to take place, which may be of much practical value as in **electroplating.**

Electrolysis. Pure water becomes an electrolyte if it contains a small quantity of sulphuric acid. This may be shown by

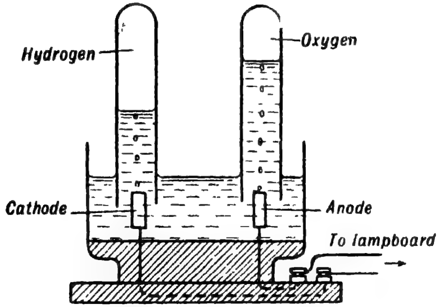


FIG. 127. APPARATUS FOR THE ELECTROLYSIS OF WATER.

means of a voltameter (Fig. 127) connected either to a lampboard and direct current mains or to a 4-volt accumulator. If the bowl contains pure distilled water, the lamps do not light

and no current flows. On acid being added to the water, the lamps light, showing the circuit to be complete, and bubbles of gas can be seen rising from the platinum electrodes. Test tubes are then filled with the acidulated water and placed over the electrodes, so that the gases are collected. It is soon observed that twice as much gas collects at the cathode as at the anode.

When the cathode test tube is filled, it is removed and tested by applying a light to it ; the gas burns with a blue flame and may give a slight pop if a little air has become mixed with it. As will be seen later the gas is **hydrogen.** The other test tube of gas is tested with a glowing splint : the splint relights, which suggests that the gas is **oxygen.**

In this experiment the solution contains positive hydrogen ions and negative hydroxyl and sulphate ions. (The hydroxyl ion consists of hydrogen and oxygen atoms and the sulphate of sulphur and oxygen atoms.) When the accumulator is connected to the electrodes, the positive hydrogen atoms drift towards the cathode and hydrogen gas is evolved there. The hydroxyl and sulphate ions drift towards the anode, where the hydroxyl ones are discharged and decompose into oxygen and water. Thus oxygen is given off at the anode. The amount of acid remains unchanged, so this experiment is often called the electrolysis of water, and the relative amount of the gases (twice as much hydrogen as oxygen) is taken as evidence that a molecule of water consists of two atoms of hydrogen and one of oxygen.

Electroplating. If a metallic ion travels to the cathode of a voltameter, a thin layer of the pure metal will form there as an even plating. Thus with a solution of copper sulphate, the positively charged copper ions travel to the cathode during electrolysis, while the negative sulphate ions travel to the anode ; if the latter is made of copper, the sulphate ions combine with it to form fresh copper sulphate solution, so that the strength of the solution does not change.

EXPT. 43. **Copper plating.** *Dissolve some copper sulphate in water to make a solution ; filter it and pour it into a large vessel. Take a copper plate as the anode and connect it by wires to the positive terminal (marked red) of a 4-volt accumulator. Take an old spoon or a key, clean it thoroughly with fine emery paper, and connect it to the negative terminal of the cell, so that it forms the cathode (Fig. 128). Pass a current for half an hour, and a thin coating of copper will be found on the spoon or key.*

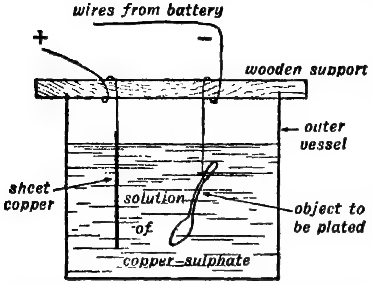


FIG. 128. APPARATUS FOR COPPER-PLATING AN OBJECT.

If the spoon copper plated in Expt. 43 were afterwards placed in a solution of *nickel ammonium sulphate* with the spoon again as the cathode, a deposit of **nickel** would be formed. Similarly with other forms of electro-plating ; a layer of any particular metal is obtainable if a suitable solution is used in the electro-plating bath. When this is done on a commercial scale, a number of articles are plated at once, and the anode is made of the same metal as that to be deposited from the solution so that it can be dissolved by the negative ions and the strength of the solution remain unchanged. Thus for **silver-plating**, a solution of the double cyanide of silver and potassium is put in the electro-plating bath, and a silver anode is used. Before articles are electroplated, great care must be taken to clean them thoroughly ; they are scrubbed with wire brushes or sand, and washed in dilute sulphuric acid.

Electro-typing. Another application of electrolysis is in the making of copies of type. Printers often want to set up their type afresh but still want to retain copies of pages of type already set up, so that they can continue to print books from them. To make these copies (or " electros ") a mould is first obtained by pressing wax on to the type. This mould is then coated with graphite to make it conducting, and used as a

cathode in a copper sulphate bath. When a hard layer of copper has been deposited, the wax is removed, and a type-metal backing given to the copper to strengthen it. Such a plate is a good copy of the original type, and can be used for actual printing, while the type is set free for further use. Most books which run through large editions are printed from electrotypes in this way.

Aluminium. Until twenty years ago, aluminium was a comparatively rare metal, because it was difficult to separate from the natural clay in which it occurred. Now it can be obtained by electrolysis and immense numbers of domestic utensils are made from it. To separate it, the clay is mixed with another mineral, and a powerful current passed through the molten mixture, so that aluminium is deposited at the cathode. It is interesting that the British Aluminium Works are situated near the Caledonian Canal, where the Falls of Foyers give water power which can be used cheaply to drive the dynamos generating the electric current needed for the industry.

CHAPTER X

STATIC ELECTRICITY. THUNDERSTORMS. PASSAGE OF ELECTRICITY THROUGH GASES. NEON TUBES. ELECTRONS. X-RAYS

Electrification by friction. Most people have heard the crackle and seen the tiny blue sparks produced when the hair is combed in a dark room in dry and frosty weather. Similarly a silk petticoat may crackle when taken off, and it may billow out in a curious fashion. Such effects are due to electricity produced by friction, and as early as 600 B.C. Thales of Miletus recorded that amber that had been rubbed with wool attracted light objects. Much later on **Dr. Gilbert** (1540-1603), a physician to Queen Elizabeth, found that a great variety of other substances such as glass, sealing-wax and sulphur, could behave in the same way as amber. He called the effect **electrification** from the Greek word "elektron", meaning "amber", and a body which, like amber, has acquired this property of attracting light objects is said to be *electrified*, or to *possess a charge of electricity*. Since this electricity does not flow like a current, but remains stationary on the body, it is known as **static electricity.**

Positive and negative electricity. If vulcanite is rubbed with cat's fur and glass with silk, they will both acquire the property of attracting small pieces of tissue paper, but they will not be electrified quite in the same manner.

EXPT. 44. **Electrification.** (*a*) Rub a vulcanite rod with cat's fur and suspend it by silk thread in a paper stirrup. Now rub a second vulcanite rod in the same way and bring it up to the suspended one. Notice that the latter is repelled.

(*b*) Take a glass tube that has been well dried in a warm place and rub it with silk. (All apparatus for electrostatic experiments should be thoroughly dried or the charges will leak away.) Bring the glass tube up to the suspended vulcanite rod, and notice that the latter is attracted.

(*c*) Suspend a pith ball by a silk thread (Fig. 129) and bring an electrified vulcanite rod near it. Notice that the ball is first attracted, but after touching the vulcanite rod and receiving some of its charge, it is repelled.

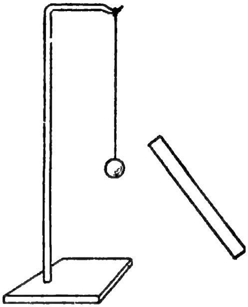


FIG. 129. A PITH-BALL ELECTROSCOPE.

(*d*) Take a flannel cap which has a long silk thread attached to the end, and place it over the end of a vulcanite rod. Twist the thread round the cap and pull it so that the cap rotates and rubs the vulcanite rod. Leave the cap in position and bring both up to the suspended pith ball used in (*c*). They have no effect on the pith ball and *appear* to be uncharged. Now separate them holding the flannel cap by the silk thread. Both will be found to have an effect on the pith ball and to be electrified.

These experiments on electrification show that there are two kinds of electricity causing attraction and repulsion, rather like the opposite polarities occurring in magnetism. **Franklin** (1706-1790) called these two kinds positive and negative, and we define a *positively electrified* body as one which behaves like a *glass rod rubbed with silk* and a *negatively electrified* one as one which acts like *vulcanite rubbed with fur*. Experiment shows that **like charges repel each other but unlike charges attract each other.** When the flannel rubber and a vulcanite rod are kept together, apparently no electrification is produced, because the *amounts of each kind of electricity produced by friction are equal*, and neutralise one another; when the rubber and the rod are tested separately they are each found to be electrified.

The electroscope. The suspended pith ball is a simple kind of electroscope, that is, an instrument for detecting electric

charges. A better form is the **gold leaf electroscope** (Fig. 130). This consists of a metal rod having a metal plate at one end and a strip of gold leaf (or Dutch metal) at the other, the rod being supported in a block of sulphur or vulcanite in the top of a glass fronted box. The sulphur or vulcanite acts as an insulator to prevent charges given to the rod from leaking away, and the box protects the gold leaf from being disturbed by draughts. When a charge is given to the rod, the gold leaf moves away from its lower end, because it is charged similarly to it and is therefore repelled.

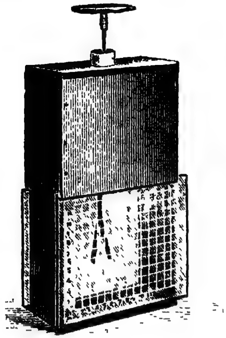


FIG. 130. A GOLD-LEAF ELECTROSCOPE.

CONDUCTORS AND INSULATORS

EXPT. 45. **Conductors and Insulators.** To test if various substances are conductors or insulators, take a gold leaf electroscope and give it a negative charge by rubbing the top plate with an electrified vulcanite rod. The gold leaf rises because the charge distributes itself throughout the rod and gold leaf, so that the latter is repelled. Now take a variety of substances, sealing-wax, iron, sulphur, paper, rubber, dry cotton, wet cotton, dry silk, wet silk, porcelain, brass, etc., and test each to find if it is a conductor or insulator, by touching the plate of the electroscope with it. If it is a conductor, the charge of the electroscope will pass along it and through the person holding it to the earth ; the leaf of the electroscope then falls quickly. If the substance is a partial conductor the leaf will only fall slowly and if it is an insulator there will be no change in the electroscope. If necessary, the electroscope must be recharged between tests. Classify the various substances in three columns thus:

Conductors	Partial conductors	Insulators

Metals are conductors ; dry cotton and moist silk are partial conductors ; sealing-wax, rubber and dry silk are insulators. If *any* substance is insulated so that the charge on it cannot leak away it may be electrified ; this is an important difference from magnetic properties which are peculiar to iron and steel.

Electrostatic Induction. Just as the attraction of unmagnetised pieces of iron or steel is explained by magnetic induction, so in a similar way, the attraction of light objects by an electrified body is due to electrostatic induction.

EXPT. 46. **Electrostatic induction.** Take a long metal cylinder supported on an insulating ebonite rod. Touch the cylinder so that any charge on it flows to earth and is thus removed. Hold an electrified vulcanite rod near one end of the cylinder (Fig. 131) and touch each end of the cylinder in turn with a proof-plane (a small disc of metal with an insulating handle). Test the charge on the proof-plane by bringing it up to an electroscope which has been charged negatively. If the proof-plane is charged negatively the gold leaf will diverge more when the proof-plane is brought near ; if the charge is opposite (or if the proof-plane were uncharged) the leaf would fall. To make a sure test of positive charge it is better to recharge the electroscope positively and test for increased divergence. It is found that the end of the cylinder nearer the rod has a positive charge and the further end a negative one.

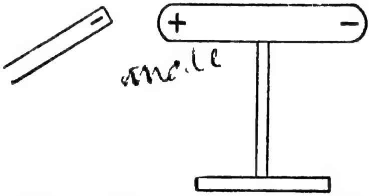


FIG. 131. ELECTROSTATIC INDUCTION.

While still holding the vulcanite rod in position, touch the cylinder with the hand and so connect it to earth. Then remove the rod and test the charge on the cylinder. It will be found to be charged positively throughout and is said *to have been charged positively by induction.*

Pieces of paper are attracted by a charged body because the latter induces an opposite charge in the side of the paper that is nearest, and a like charge to the side farther away. This like charge may be so repelled that it may leak away if it is in contact with a fairly good conductor, and then the paper,

having an opposite charge to the charged body is attracted to it.

If an insulated conductor like the cylinder in Expt. 46 is touched to earth while induced charges are being produced in it by a charged body, the induced charge of a like kind flows away and an induced charge of an opposite kind is acquired; this then distributes itself uniformly throughout the conductor when the influencing body is removed. This is the best way of charging an electroscope and Fig. 132 shows the

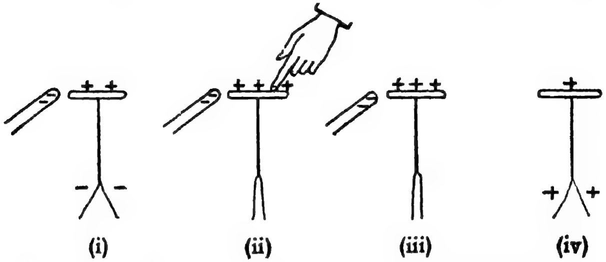


FIG. 132. HOW TO CHARGE A GOLD-LEAF ELECTROSCOPE POSITIVELY BY MEANS OF A NEGATIVELY-CHARGED ROD.

various stages in charging a gold leaf electroscope positively by using a negatively-charged vulcanite rod.

Electric potential. The effect of electric induction shows that the influence of an electric charge is felt at a distance away from it; hence an **electric field** is said to exist round a charged body. The *direction* of the electric force at any point in the electric field is given by **electric lines of force,** and the *magnitude* of the force is represented by the number of the lines. Since this force exists, it would be necessary to do work to move a charge about in the electric field and so all parts of the field are said to have a certain electric **potential.** If there is a difference of potential, electricity will flow from the place of greater potential to that of less, just as a stream of water flows from a higher level to a lower. The electric pressure described in Chapter IX as being produced by a voltaic cell or a dynamo and causing a

current to flow is the same thing as a difference of potential. At all points in an electric circuit, there must be a potential difference if a current is to flow; this potential difference is measured in volts. Ohm's Law is true for any part of a circuit, and relates the potential difference for that part of the circuit with its resistance and the current flowing through it.

Distribution of charge on a conductor. If a conductor is insulated like the one used in Expt. 46, a charge distributes itself about it until the potential is uniform everywhere, but it cannot flow away to earth. The actual distribution of the charge and of the lines of force depends, however, on the *shape* of the conductor. This may be verified by taking charges with a proof plane from the surface of a sphere, and from the surface of a pear-shaped conductor. Equal charges can be taken from all parts of the former, but with the latter the charges taken from the more sharply curved end are larger and produce more divergence of the leaf of the electroscope. There is a tendency for charge to accumulate at points, and the sharper the point, the more electricity accumulates there.

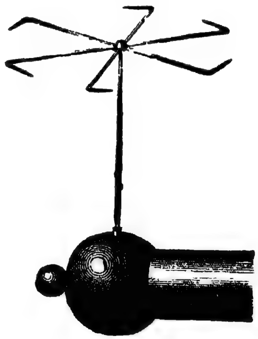


FIG. 133. HAMILTON'S MILL.

EXPT. 47. **Discharge from points.** (*a*) Attach a needle to one terminal of a Wimshurst machine (a machine for producing electrostatic charge) and connect the other terminal to earth. Turn the machine and hold the flame of a candle near the needle point: note that it is blown away from the point, because the air near is so strongly electrified that it is repelled away from the needle.

(*b*) Attach a Hamilton's Mill (Fig. 133) to the terminal of the machine and notice how it rotates in the opposite direction to that of the repelled air currents.

Thunderstorms. Air is generally an insulator, but if the lines of force become very crowded, it may cease to be so, and opposite charges may leap across a gap and neutralise one

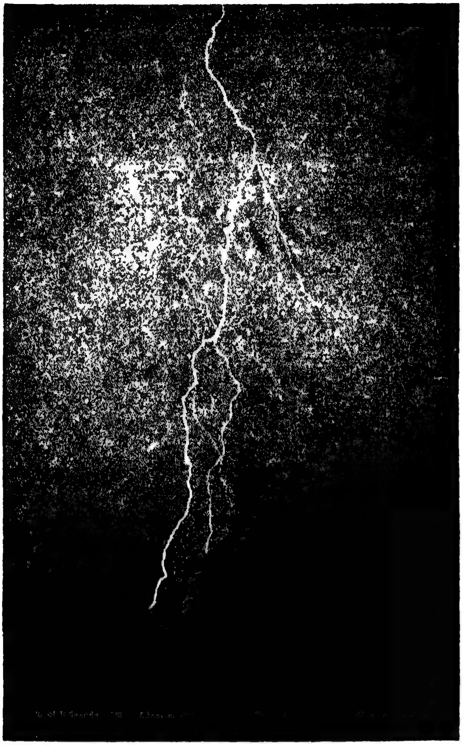


FIG. 134. LIGHTNING.
(*Photo: Dr. W. J. S. Lockyer.*)

another. Thus an electric spark passes. It may be a small one like that produced by a Wimshurst machine or it may be several miles long like a flash of lightning in a thunderstorm (Fig. 134), but it is the same kind of effect except that a much greater potential difference is required for the longer spark. Franklin was the first scientist to suggest that lightning was due to an electric spark on a large scale, and he tested his theory by flying a kite made from a silk handkerchief in a thundercloud. The lower end of the kite string was attached to an insulating

silk ribbon, which he held, and to a key. He then found that when the kite string was wet he could obtain sparks by placing his knuckle near the key, the sparks being precisely similar to those produced by his electric machine. Actually, the experiment was a dangerous one, and later on a Russian scientist, trying a similar experiment with a tall metal rod above his house for obtaining electricity from the clouds, was killed by a charge from the lower end of the rod.

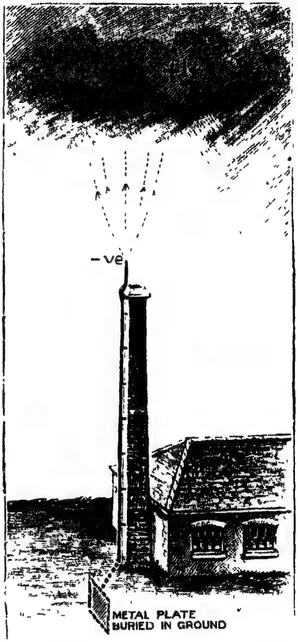


Fig. 135. A Lightning Conductor.

During a thunderstorm the clouds are charged electrically, and there may be a discharge between different clouds, or a charge of an opposite kind may be induced on the earth's surface, and then if the potential difference is great enough a dart-like flash from the cloud passes to the earth, and the main flash then passes from the earth to the cloud. The intense heat in its path makes the air incandescent so that the light is seen, and the violent expansion of the heated air in its path causes the crackle of the thunder. The continued rumble of the thunder is due to the reflection of the sound from the clouds and from the earth, and in a hilly district the effect is more pronounced. The reason for an interval of time elapsing between the lightning and the thunder was explained in Chapter VI.

Lightning conductors. The electricity from the clouds will preferably pass to the earth by the easiest path or earth-connected conductor ; thus tall spires, chimneys, and isolated trees are most likely to be struck by lightning. To lessen the

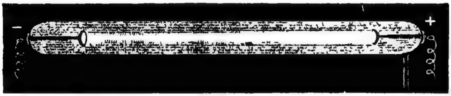
danger to a building, a lightning conductor consisting of a thick copper rod is fixed so that its upper end projects above the building, and its lower end is connected to a large metal plate buried in moist earth (Fig. 135).

It was shown in Expt. 47 that electric charge accumulates at a point and a stream of charged air is repelled from it. For this reason the top of a lightning conductor consists of one or several points so that, if a positively charged thundercloud is near it, the induced negative charge on the earth and conductor flows from the points as a steady stream of electrified air. This partly neutralises the cloud, and makes it less probable that a flash of lightning will take place. Thus a lightning conductor protects a building because it prevents the accumulation of powerful charges in its neighbourhood.

Conduction of electricity in gases. It seems, then, that although air is generally an insulator, it ceases to be so under the strain of a big potential difference and so a spark may pass through it. If the air is contained in a vessel from which it can gradually be removed, the nature of the spark will change as the pressure is reduced and the air becomes more rarefied.

EXPT. 48. **Electric spark in rarefied air.** Take a tube about 60 cm. long having two electrodes sealed into it, and a side tube leading to an air-pump by means of which the air may be removed (Fig. 136). Connect the electrodes to the terminals of a Wimshurst

cathod



anode

FIG. 136. ELECTRICAL DISCHARGE THROUGH A RAREFIED GAS.

machine, so that a big potential difference can be produced between the electrodes. When the air is at atmospheric pressure, the distance may be too great for a spark to pass. Now start the air-pump working, until the pressure inside the tube is considerably reduced ; a discharge will then be seen in the tube in the form of a narrow band of crimson light. Continue the pumping and this band will spread out until a crimson glow fills the tube.

The experiment shows that an electric discharge takes place more readily through rarefied air than through air at ordinary pressures, and the form of the discharge is that of a band of glowing gas rather than the jagged irregularity of the ordinary spark. The colour of the discharge varies according to the gas in the tube, each gas having a characteristic colour.

Neon tubes. In recent years, the electric discharge in a rarefied gas has been used to a great extent for advertisement signs. Neon is the gas most frequently used in the tubes made for this purpose, and it has a characteristic red-orange glow. Generally such tubes require a much higher voltage between their electrodes than can be obtained from the ordinary mains, and so they have to be connected to a transformer, an instrument by means of which the ordinary 230-voltage can be converted to a 1000 volts or more.

A further development of the discharge tubes is that of hot electrode tubes. In these, the electrodes are heated, and the tubes can then be used on the ordinary supply mains. The flood-lighting of buildings in colour is carried out by this means, different rarefied gases being used in the lamps to obtain the various colours.

Electrons. Although since the time of Dr. Gilbert, scientists have gradually discovered more and more about electricity they were unable to form any satisfactory theory of the nature of electricity until the end of the last century. Then experiments on the discharge of electricity in a gas led to the discovery that when the pressure in a tube is reduced to a much greater extent than in Expt. 48, the gas ceases to be luminous and an invisible stream of particles is projected at a great speed from the negative terminal or cathode. These **cathode rays**, as they are called, consist of minute particles of negative electricity called **electrons**; they are obtained by discharge through a rarefied gas because some of them get detached from the atoms remaining in the tube by the electric force existing. They can be detected by the fluorescent effect they produce on

the glass of the tube; if an obstacle is placed in their path a direct shadow is caused in the fluorescence (Fig. 137) which indicates that they travel in straight lines.

In Chapter IX, mention was made of the electrical nature of the atom. Scientists are still working to-day to find out more about this, but a simple idea (although an incomplete one) is that the atom is made up of a central nucleus of positive electricity with a varying number of electrons grouped in some way about it. Atoms of different elements vary only in the amount of charge on the nucleus and the number of electrons around it.

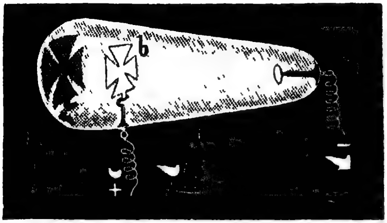


Fig. 137. The Shadow caused by an Obstacle in the path of Cathode Rays.

The electrons are so small that the size of each is only $\frac{1}{1845}$ of that of a hydrogen atom, hydrogen being the simplest and smallest atom.

In the ordinary way, the negative charges of the electrons are equal to the positive charge of the nucleus, so that the whole atom is neutral or uncharged. But in conductors, there are often free electrons which have become separated from their parent atoms, and the latter are then positively charged. If then a negative charge is brought up to the conductor, the positively charged atoms, which are immovable, stay at the end nearest the negative charge, while the free electrons stream away to the far end. When the charge causing induction is removed, they return to their original positions because they are attracted by the positive atoms. This explains electric induction, and similarly a current of electricity is regarded as a flow of free electrons in a conductor under the influence of electric pressure.

X-rays. In 1895, **Röntgen** discovered that when a stream of cathode rays strikes the glass of the tube they give rise to

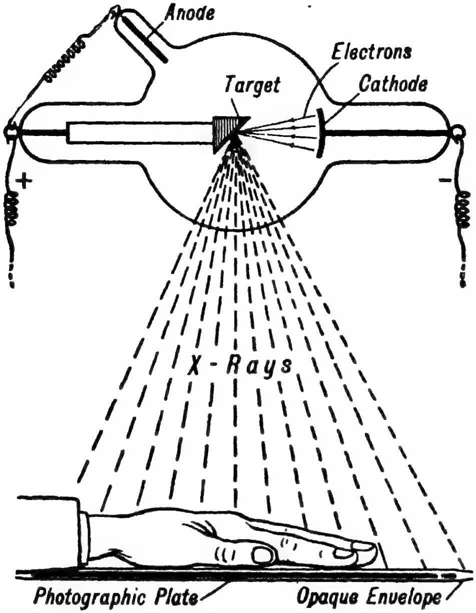


FIG. 138. HOW X-RAYS ARE USED FOR TAKING A PHOTOGRAPH.

another kind of radiation called X-rays or Röntgen rays. These rays have been mentioned in Chapter VI as a type of electro-magnetic waves of exceedingly short wave-length.

To produce X-rays, a platinum or tungsten target (called an **anti-cathode**) is set in the tube (Fig. 138), so that the stream of electrons from the curved cathode are concentrated on to it. X-rays then radiate out from the anti-cathode. They have a peculiar property of penetrating substances which are impenetrable to ordinary light; thus they pass through cardboard, wood, leather and flesh and even metals in varying degree. Moreover, they affect a photographic plate in a similar way to light waves, so that X-ray photographs can be taken (Fig. 139), showing bone, flesh and metal of varying shadow according to

FIG. 139. AN X-RAY PHOTOGRAPH OF A FOOT INSIDE A BOOT

the way in which X-rays penetrate these substances. X-rays also produce fluorescence on a barium platinocyanide screen, and similar shadow effects can be seen on such a screen without an actual photograph being taken.

Both doctors and dentists make use of the screen and the photographic effects of X-rays in order to observe defective structures in bones, teeth and various organs that they cannot see in the ordinary way. To examine the alimentary tract the patient is given a meal containing a preparation of bismuth or barium which is more opaque to the X-rays than the surrounding tissues. Similarly, an injection of a preparation of iodine is given if an examination of the lungs or nasal sinuses is necessary.

X-rays are also used for therapeutic purposes. Malignant growths are rapidly growing ones and these are more sensitive to the radiation than the surrounding tissue, so that their growth may be arrested by it.

CHAPTER XI

COMPOSITION OF MATTER. MIXTURES AND COMPOUNDS. SOLUTIONS. COLLOIDS. OSMOSIS. CAPILLARITY. SURFACE TENSION

Composition of matter. Our study of electricity has taught us that everything in the world around us is made up of atoms, the atoms themselves being electrical in nature. They are, so to speak, the bricks with which all the different substances, such as the stones, flowers, plants and animals, are built up. Sometimes a substance consists of atoms only of one kind, and it is then said to be an *element* ; there are ninety-two such elements in the world. More often a substance consists of two or more kinds of atoms ; hence, an immense variety of substances known as **mixtures** and **compounds** exist. Two of the most common substances we know are air and water ; air is a *mixture* of gases, chiefly nitrogen and oxygen ; water is a *compound* of the gases hydrogen and oxygen. Before learning more about mixtures and compounds, it is necessary to distinguish between physical and chemical changes.

Physical and chemical changes. All substances may undergo either kind of change—chemical or physical. It has been seen that ice may turn to water and water to steam ; a wire may become white-hot as in the filament of an electric lamp ; a needle may be made magnetic so that it attracts iron filings ; a vulcanite fountain-pen can be rubbed so that it attracts small pieces of paper. Such changes as these are **physical changes,** because the actual substance remains unaltered, and it is usually quite easy to reverse the change and bring the substance

back to its original state. Thus steam can be cooled to form water and water to form ice ; the filament of the lamp becomes normal when the current ceases ; the needle may be made to lose its magnetic properties by making it red-hot.

A change of a different type takes place if a match or a piece of magnesium ribbon is burnt. In the former case the white wood changes to a piece of black carbon ; in the latter case, the grey metal burns with a brilliant white light and turns to white ash. These are **chemical changes**, because new substances with new properties are formed, and it is difficult or impossible to convert them back into the original substances.

Mixtures and compounds. If two elements, such as iron and sulphur, are taken, either a mixture or a compound may be formed.

EXPT. 49. **A mixture and a compound.** (*a*) Take some iron filings and some powdered sulphur. Mix them together and study the substance obtained. Bring a bar-magnet up to it, and notice what occurs.

(*b*) Take some of the mixture of iron and sulphur and heat it in a hard glass tube. Notice that it becomes red-hot and glowing. When the product of heating has cooled, examine it carefully, and test it with a bar-magnet. Put a little in a test tube and add some dilute sulphuric acid ; smell the gas obtained. Treat some iron and some sulphur in a similar way with acid.

A careful examination of a *mixture* of iron and sulphur shows that the particles of each element can be seen lying side by side, and by means of a magnet, the iron can be separated again from the mixture. The substance obtained when the iron and sulphur are heated is quite different from either of the elements ; it is not affected by a magnet, and the gas given off when sulphuric acid is added to it smells of bad eggs. In this case a chemical change has taken place and a **compound** of iron and sulphur has been formed. Both the mixture and the compound contain atoms of iron, and sulphur, but they are bound together in different ways ; molecules of iron and of sulphur still remain in the *mixture*, but in the *compound* new molecules con-

taining both iron and sulphur atoms are formed by chemical combination. (A molecule was defined on p. 143.) The laws of chemical combination will be studied in Chapter XIV, and it will then be seen that in a compound the substances combine in a certain definite proportion. In a mixture any varying amount of either constituent may be used.

Thus the important differences between mixtures and compounds are that the constituents of a mixture are in any proportion and may be separated by simple mechanical means, whereas the constituents of a compound are of a definite proportion and have combined chemically to form a new substance having new properties. Air, garden-soil and brass are mixtures, but sal-ammoniac and copper sulphate are compounds.

Solution. When a lump of sugar is placed in a cup of tea, it gradually disappears and the tea becomes sweetened. A solid **dissolves** in a liquid to form a **solution**, the nature of the solution depending on both the substance dissolved, that is, the **solute**, and the liquid in which it dissolves, that is, the **solvent**. Sometimes particles of a solid are **insoluble** and then they may remain suspended in the liquid. Such particles are in **suspension**; they can be removed by filtration. Special paper is fitted into a glass funnel, and the liquid is poured through (Fig. 140); the solid particles are left on the filter paper as a residue, while the liquid passes through the pores of the paper. The liquid is the **filtrate**, and if a substance is *in solution* in the liquid, it is still present in the filtrate and is not removed by filtration.

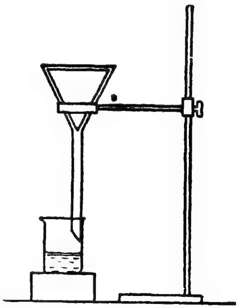


FIG. 140. APPARATUS FOR FILTRATION.

Since there is often no visible change in a liquid when it has become a solution, the presence of the dissolved solid may have to be detected by **evaporation**. This consists in heating the liquid in an evaporating dish until all the solvent passes off as vapour,

while the solid is left in the dish. If the solvent is to be regained from the solution the vapour must be made to condense again by **distillation.** Thus by evapcration and by distillation both parts of a solution, the solute and the solvent, may be separated out again.

EXPT. 50. **Solution of various substances in water.** Obtain a number of common household substances, such as salt, sugar, sand, plaster of Paris, washing soda, starch, borax. Shake up a small quantity of each substance in turn with distilled water in a test tube. If any solid remains undissolved, filter the mixture by pouring it down a glass rod on to a filter paper fitted in a funnel in a filter stand. Collect the filtrate in an evaporating dish.

If the substance is soluble in cold water, the liquid in the dish should be a solution. To test this, evaporate it to dryness so that all the water is driven off and only the dissolved solid remains. A quick way of evaporating a little of the solution is to dip a clean glass rod into it, and then to dry the rod in the warm air above a bunsen flame. If the rod remains clean, there was no dissolved solid in the liquid.

Water is a very good solvent and many common substances, such as sugar, starch, salt and soda, dissolve in it. Sand, glass, metals and wax are insoluble in water although metals are soluble in an acid and wax is soluble in petrol ; this fact is made use of when grease stains are removed with petrol.

When washing crockery and glassware, it is important that it be wiped quite dry. because otherwise the evaporation of the surplus water leaves a solid residue on the surface, just as a glass rod dipped in a solution retains dissolved solid when dried.

Saturated solutions. Some substances are only slightly soluble in cold water ; they may dissolve more readily if the water is warmed.

EXPT. 51. **Effect of heat on solution.** Half fill a test tube with distilled water and add to it a small quantity of nitre. Shake well, adding more nitre until some remains undissolved ; such a solution is a *saturated* one. Warm the saturated solution and see if the undissolved solid disappears. If it does, add more nitre and shake well until a saturated solution is again obtained at the higher

temperature. Observe how very much more solute is required to make a hot saturated solution than a cold one. Leave the solution in the test tube to cool. Repeat the experiment with salt and lime.

A **saturated solution** at a certain temperature is one in which the solvent can dissolve no more of the solid at that temperature. Most substances are considerably more soluble in hot water than in cold. Salt is an exception and very little more dissolves in hot water than in cold, while in the case of lime, only a very small quantity dissolves in cold water and even less in hot.

Separation by solution. Substances soluble in one solvent may, or may not, be soluble in another. Sugar and salt are both soluble in water; yet salt is insoluble in methylated spirit, while sugar is soluble. When two substances are not both soluble in a certain liquid a mixture containing both of them may be separated by using the liquid as a solvent.

EXPT. 52. **Separation of sand from a mixture of sugar and sand.** Take about 10 gm. of the mixture and put it in an evaporating dish. Add distilled water and warm gently, stirring until all the sugar is dissolved. Filter the mixture, and if some of the sand remains at the bottom of the dish, rinse with water, and so wash all the sand on to the filter paper. Pour hot water through the filter in order to free the sand from all traces of sugar solution; otherwise particles of sugar will appear on the sand when it is dry. Dry the filter paper and its contents in an oven, and so obtain the dry sand. The sugar may be regained from the solution by evaporation.

Distillation. Since the dissolved solids in a solution are left in the vessel when the solution is evaporated, the pure solvent passes off as vapour. If the vapour is then cooled it condenses and a pure liquid is obtained.

The process of **distillation** may be illustrated by setting up a flask and a condenser (Fig. 141). The continual flow of cold water through the condenser keeps the inner tube cool, so that the vapour passing down it from the boiling water in the flask is cooled and condensed. If salt and potassium permanganate

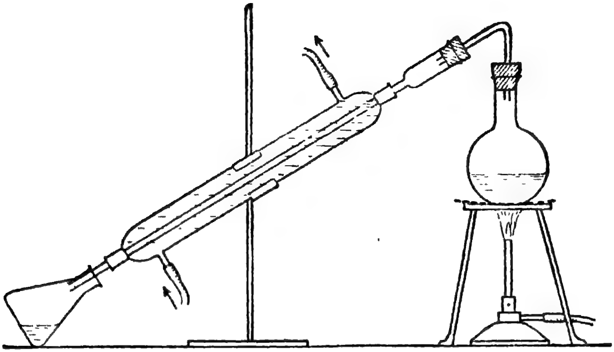


FIG. 141. APPARATUS FOR DISTILLATION.

are added to the water in the flask, the distilled water in comparison is both tasteless and colourless, and if it is evaporated to dryness, no residue will be found.

In this way, pure water can be obtained from sea water, but although many ships carry a distilling plant, the process is slow and would only be used in an emergency. The process is also of importance in the manufacture of alcohol and of sugar and in many other industries.

Solution of gases in liquids. The sharp taste of soda water or mineral waters is due to the carbon dioxide gas dissolved in them. The amount of gas the water will absorb is greater for higher pressures than for low; hence in making soda water the water is brought into contact with the gas under high pressure. As soon as the pressure is released, that is, when the bottle or siphon is opened, there is the characteristic effervescence; bubbles rise and the gas passes out of the solution. Even when such action ceases there is still a slightly acid taste which shows that some of the gas remains dissolved.

Another common example of a dissolved gas is that of air in ordinary tap or spring water. The air gets dissolved when the water is passing through it in the form of rain and its presence is essential for the plant and animal life existing in water. Fish,

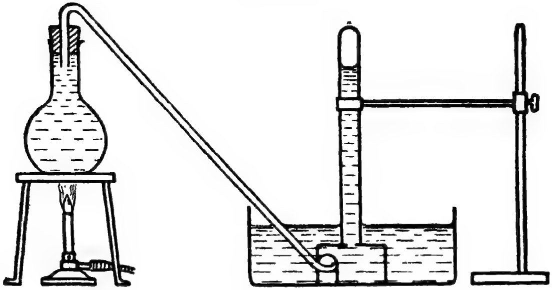


FIG. 142. DISSOLVED AIR IS PRESENT IN TAP WATER.

for example, pass aerated water through their gills and so obtain the oxygen they need for breathing.

When water is warmed, the first small bubbles seen to rise through it are bubbles of air, and the flat taste of boiled or distilled water is due to the absence of dissolved air. The presence of this air can be shown by the apparatus of Fig. 142. The flask and tubes are completely filled with tap water and the water in the flask is boiled for some time. Any steam formed condenses again in the cold water of the trough but some gas collects in the tube. This, when tested, proves to be air.

Solution of liquids in liquids. As well as solids and gases dissolving in a liquid, it is possible for one liquid to dissolve in another. For example, alcohol, glycerine, and, to a certain extent, ether, are all soluble in water, and a clear homogeneous solution like a solution of sugar in water can be obtained.

In certain cases, however, the mixture of two liquids results in a turbid liquid which is not a true solution. Thus if turpentine is shaken up with water, it may appear to dissolve but actually the oil breaks up into tiny globules which remain in *suspension* in the liquid, and form an **emulsion.** When the liquid is left to stand, the drops tend to join up, so that the two liquids separate again, the oil rising to the surface. Similarly,

milk is an emulsion, its colour being due to droplets of fat in suspension in a watery liquid ; many of these rise to the top as cream when the milk is allowed to stand.

Colloidal solutions. Solutions like milk, which are not *true* ones, because the dispersed particles are not small enough for a clear liquid to be formed, are known as **colloidal solutions.** If the particles in such a solution are too small to be visible with a microscope, the liquid is a **true colloid**; if, as in milk, the particles are visible and liquid, the fluid is said to be an **emulsion.** If the particles are visible and solid (for example, soot in water), the fluid is said to be a **suspension.**

The particles often depend for their stability on the presence of some other substance to keep them dispersed. A certain separation occurs in milk when the cream rises, but the casein and calcium salts present help to keep the particles of fat suspended. Salad dressing is an emulsion of oil and vinegar which requires egg or mustard to maintain it as a stable colloidal solution.

Many colloids occur naturally in plant and animal life, as, for example, milk, white of egg, glue, starch, and rubber latex (the milky juice of the tree). Such colloidal solutions may coagulate or evaporate to form solid or semi-solid masses called gels. Thus white of egg, on being heated, coagulates from a colloid to form a gel, and liquid glue can change to a harder kind of gel, a toffee-like substance. Many plants and animal tissues are flexible gels formed from colloids.

To distinguish between colloids and true solutions, they are tested to see how they diffuse through a membrane into water. **Diffusion** is the movement of molecules of gases or liquids which causes them to become mixed ; thus it is obvious that a gas such as ether vapour has diffused through the air, when it can be smelt everywhere in a room. Or if a crystal of copper sulphate is put in some water, the blue solution that is formed as the crystal dissolves can be seen to spread and diffuse through the water.

EXPT. 53. **Diffusion of solutions through a membrane.** Take a funnel and cover the mouth with a piece of soaked parchment paper, or a pig bladder, tied on securely with waxed thread, so that the apparatus is watertight (this is a **dialyser**). Pour a solution of potassium iodide and starch into the funnel, and suspend it in a vessel of distilled water, so that the parchment paper is below the level of the distilled water (Fig. 143). Leave for half an hour to test how the starch solution and the potassium iodide diffuse through the membrane. Then add chlorine water to the water in the vessel and a yellow colour will be seen; this is due to iodine liberated from the potassium iodide by the chlorine water. This shows the potassium iodide solution has passed through the membrane. A test for starch is that it gives a blue colour with iodine, and the fact that the iodine in the outer vessel retains its yellow colour shows the absence of starch. The starch solution, then, has not passed through the membrane.

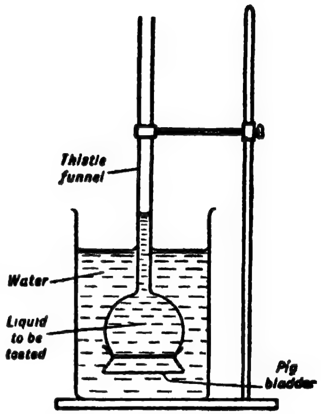


FIG. 143. DIFFUSION THROUGH A MEMBRANE.

A solution like the potassium iodide, which readily diffuses through a porous membrane, is a true solution or a **crystalloid**, while one, like starch, which does not do so, or does so only with difficulty, is a colloid.

Osmosis. The process by which two liquids or two gases separated by a porous partition may yet diffuse into each other is called **osmosis**, and it is by this means that water passes through the cell walls of the root hairs of plants. This water from the soil is needed partly to keep the plant rigid (it will wilt and droop if waterless), and partly to provide food for it from the various compounds that are dissolved in the water by its contact with the soil.

EXPT. 54. **Osmosis.** Fix up similar apparatus to Expt. 53, but this time pour a solution of diluted golden syrup into the funnel. Make a mark on the stem of the funnel to show the level of the syrup.

The outer vessel contains water as before. Diffusion takes place, and the coloured syrup can be seen to have passed through the membrane into the water. But in addition, the level of the liquid in the stem of the funnel rises, so that there is more water that has diffused *in*, than syrup that has diffused *out*.

This experiment shows that diffusion can take place in both directions through a porous membrane, and where there are solutions of different concentrations on each side of it, the tendency is for the total amount of liquid all to be of the same concentration. Hence more water passes in than syrup out, and it is the *weaker* solution that tends to pass more readily through the membrane.

In the case of a plant, the syrup is like the cell contents of the root hairs and the parchment is like the membrane of the cell wall. As in the experiment, the soil-water passes through the membrane into the root hairs, and also passes from cell to cell by osmosis. In the case of the plant, however, the cell contents do not, like the syrup, pass out into the soil, and the membrane is only semi-permeable, *i.e.* there is diffusion through it only in one direction.

Capillarity. Once water has entered the roots of a plant by osmosis, one of the factors that helps it to rise up the stem is the effect of **capillarity.** This can be illustrated by taking a number of fine tubes of different bore, and supporting them so that their ends dip into coloured water (Fig. 144). The water rises to varying extents in them according to their diameters, in contradiction to the fact of normal water-level as discussed in Chapter III. The reason is that when water or some other liquid is contained in a fine tube, a contracting force at the surface known as **surface tension** acts against the weight of the column of water, and water is drawn up the tube until the forces due to surface tension and to gravity neutralise one another.

Thus by capillarity water rises in the minute capillary passages or ducts that traverse the stem of a plant. Many other

common phenomena of everyday life are due to the same cause. For example, ink is absorbed by blotting paper; oil

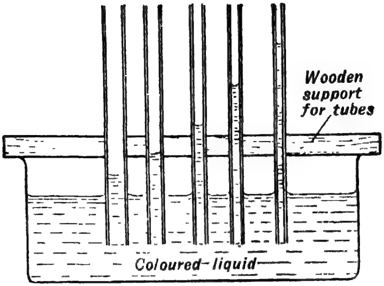


FIG. 144. THE LIQUID RISES TO DIFFERENT LEVELS IN CAPILLARY TUBES OF DIFFERENT BORE.

rises in the wick of lamps: a lump of sugar becomes saturated with moisture if only one corner of it is immersed: a piece of muslin or a towel gets completely wet if one end of it rests in a bowl of water.

Surface tension. The effect of surface tension is as if a thin skin were stretched over the surface of the liquid and pulled

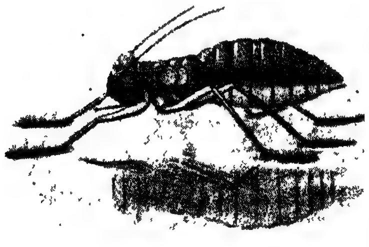


FIG. 145. AN INSECT WALKING ON THE SURFACE OF WATER.

tightly in every direction. This may be shown by scattering lycopodium powder on the surface of water in a trough, and

touching the surface of the water with the finger. The grease of the finger changes the surface tension at the points of contact, and the powder can be seen to move as if a light skin were

Fig. 146. With Drops of Mercury of varying Size, the Smallest are most nearly Spherical.

broken at these points. A small needle can be made to float on water if first supported by a thin piece of paper which can be moved gently away, and on looking at the floating needle carefully it can be seen to depress the surface slightly as if there were a skin on the water. For this reason, small insects can run on the surface of water (instead of sinking or floating according to the Law of Flotation), because their weight is too small to overcome the surface tension (Fig. 145).

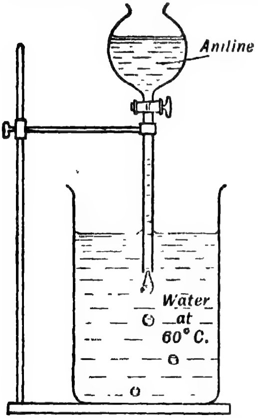


Fig. 147. Drops of Warm Aniline forming slowly in Warm Water.

Surface tension is due to the attractive forces of the molecules being free to act at the surface. The cohesive force between the molecules causes a small drop of liquid to draw itself together so that it has the smallest possible surface for a given volume; it would then be a sphere. Actually, the force of gravity acts on the drops also so that they tend to take the shape of flattened globules if their size and weight is at all appreciable. The smaller the drop, the less the influence of gravity compared with that of surface tension; hence in drops of mercury of varying size (Fig. 146) the smaller ones are the most nearly spherical. Small drops of water in the form of rain or dew are nearly spherical also.

The formation and rupture of a drop can be seen very easily if, by an arrangement of a drop funnel, drops of warm aniline are allowed to form in water that is at a temperature of about 60° C. (Fig. 147). At 64° C. aniline has a density equal to that of water, so aniline slightly cooler than this will be only a little more dense than water at 60° C. Consequently the drops forming will be almost independent of the force of gravity, because most of their weight is supported by the surrounding liquid. They can, therefore, be seen to form quite slowly, and when the narrow connecting neck ruptures, they float gently down maintaining a spherical shape under the influence of surface tension.

CHAPTER XII

THE AIR

Properties of the air. The air around us, although invisible, is yet essential for every kind of life. The early Greeks considered it to be one of the four elements fire, air, earth and water, of which they thought every other substance was composed. Nowadays our idea of the nature of things has altered, but it is still true that fire, air, earth and water are essential for human life, and if air and water ceased to exist, plant and animal life would become extinct.

Air is a *mixture* of several invisible gases, and the present chapter deals with its exact nature and composition. It has already been seen that it expands when heated, and that it has weight and exerts pressure, the pressure varying slightly from day to day in association with weather changes.

Rusting of iron. Certain common changes take place in the presence of air. One of these is the formation of a reddish-brown powder on the surface of iron exposed to the air. This **rusting** effect seems to occur most readily when the air is damp, and the change may be due to the air, or to moisture, or to both.

EXPT. 55. **Iron exposed to air-free water.** Take a round-bottomed flask, place some bright iron nails in the bottom and fill it three-quarters full of water. As was seen in Chapter XI, this water contains dissolved air; to remove this air, boil the water vigorously for ten minutes. Remove the burner, and quickly cork the flask tightly. Since the water was boiling vigorously, the steam above it will have driven all the air out from the flask, and the latter should contain only air-free water and water vapour. Leave the flask for a week, then examine it and see if the nails have rusted (Fig. 148 (i)).

EXPT. 56. **Iron exposed to dry air.** Place some of the same bright iron nails on a watch glass, and put them in a desiccator (Fig. 148 (ii)). This vessel has an air-tight lid, so that no damp air from outside can enter, and at the bottom there is a layer of calcium

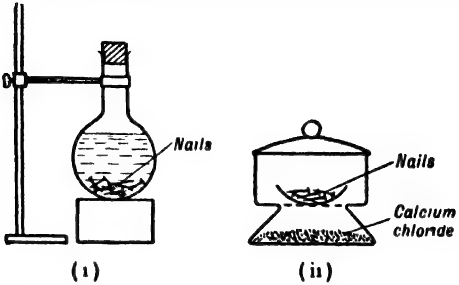


FIG. 148. IRON NAILS EXPOSED TO (i) AIR-FREE WATER AND (ii) DRY AIR.

chloride which absorbs all the moisture from the air inside the vessel. Leave the nails thus for a week: then examine them to see if they have rusted.

In neither case do the iron nails show signs of rusting, although a change soon takes place if the cork is taken out of the flask or if the desiccator lid is left off. It seems as if both air and moisture are essential for rusting.

Changes produced in iron and air by rusting. The rust that appears on iron must be due to some substance being either gained or lost by the iron. Which has occurred can be detected by weighing.

EXPT. 57. **Change of weight of iron on rusting.** Weigh a watch glass containing a heap of iron filings. Damp the filings, and leave them for some days in a place free from dust. Warm them gently in an oven or over a sandbath to ensure that they are as dry as they were at the beginning and then re-weigh.

When iron rusts there is an increase in weight, so that it appears as if some substance must have been taken from the air or from moisture so that the rust might be formed.

EXPT. 58. **Changes produced in air by iron rusting.** Damp the inside of a glass jar, place a few iron filings inside and rotate the

jar horizontally so that the iron filings adhere to the sides. Place the jar mouth downward in a trough of water (Fig. 149) and leave for a week. After some days the water is seen to have risen in the jar. Measure the height of the water in the jar above that in the basin, and, similarly the height of the jar; estimate what fraction of the air in the jar has been used up. Slide a glass cover over the mouth of the jar, lift it out of the trough, and invert it. Slide the cover to one side and lower a lighted taper into the jar.

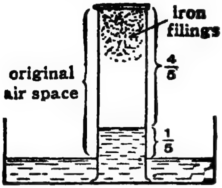


FIG. 149. IRON FILINGS RUSTING IN AN ENCLOSED VOLUME OF AIR.

Apparently about one-fifth of the air is used up when iron rusts and since a lighted taper goes out in the remaining gas, the part used up must be that which enables things to burn readily, that is, the part that supports *combustion*. The changes that take place when substances burn may be similar to the rusting of iron.

Changes produced by burning. Substances such as paper and wood burn away until only a few ashes remain. Less combustible materials, such as metals, undergo a change when heated strongly, but the change is not generally so rapid. A coloured powder appears on the part of the metal exposed to the air; on copper the powder is black, on lead yellow. Magnesium is more readily combustible than most metals, and can quickly be converted to a white powder.

EXPT. 59. **Change of weight of magnesium on heating.** Weigh a clean crucible and lid; break a piece of magnesium ribbon four or five inches long into small pieces, place in the crucible and re-weigh. Heat for some time, lifting the lid at frequent intervals to allow fresh air to get to the magnesium, but taking care that none of the white powder formed escapes. When all the metal has been converted to a white powder, leave to cool and re-weigh. From the increase in weight and the original weight, calculate the percentage increase in weight. Compare the result with other members of the class.

There is a definite *increase* in weight when magnesium is heated; and since different experiments all show an increase in the same proportion, the white powder formed must be

similar in all cases, and of a certain composition. It was seen in Chapter XI that when substances combine in a certain definite proportion a compound is formed ; thus white powder formed from the element magnesium is a compound made by the air, or part of it, combining with the metal.

EXPT. 60. **Change produced in air by phosphorus burning. (Phosphorus should be cut under water and on no account should it be touched with the fingers, or left for any length of time out of water.)** Before starting the actual experiment, place a small piece of phosphorus on a tile, ignite it by touching it with a hot wire, and note how dense white fumes are produced as it burns.

Cut a piece of phosphorus of the size of a large pea, and dry it with blotting paper. Place it in a dry crucible and float the crucible in a trough of water. Cover it carefully with a bell-jar having an air-tight glass stopper (Fig. 150). Remove the stopper and ignite the phosphorus by touching it with a hot wire. Quickly replace the stopper and observe what happens as the phosphorus burns.

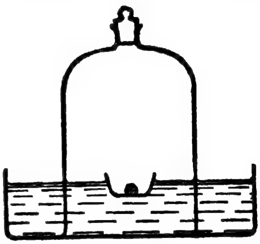


FIG. 150. BURNING PHOSPHORUS INSIDE A BELL-JAR.

Dense white fumes are formed and at first the level of the water inside the jar sinks, but it soon begins to rise slowly, and continues to do so until action ceases. Let the jar cool and the white fumes settle. Then lift the jar and measure the height of the water inside above that outside and also the height of the jar. Estimate approximately what fraction of the air has been used up by the phosphorus in burning.

To test the remaining gas, pour water into the trough until the level inside and outside the jar is the same (this prevents air entering), then remove the stopper and lower a lighted taper into the jar. Now remove the jar, invert it and shake up in it some water coloured with blue litmus solution ; the solution turns red, showing an acid is formed by a product of the burning dissolved in water.

Similar results are obtained from experiments on burning and rusting. In both cases, the substance increases in weight, and one-fifth of the air is used up, the part removed being that which supports combustion. The similar nature of the two

processes can be shown still further by the fact that chemical analysis of the white powder formed when magnesium is left exposed to damp air shows it to be identical with the white ash formed when the metal burns.

Composition of the air. The chief gases in the air are one which supports combustion, **oxygen**, and one in which a lighted taper will not burn, **nitrogen**, the proportion being approximately one-fifth of oxygen and four-fifths of nitrogen. Expressed in percentage form the composition of *dry* air by volume is as follows :

Oxygen	20·96
Nitrogen	79·00
Carbon dioxide	0·04
	100·00

Of the 79 per cent. of nitrogen, however, nearly 1 per cent. consists of argon, neon, helium and other rare gases, which are present in very small quantities. The latter are *inert* gases. that is, they do not combine at all readily with most other substances, nor do they burn or allow other substances to burn in them. Thus, as has already been mentioned, helium is used for filling airships and neon for electric lamps and signs. The amount of carbon dioxide varies when respiration and burning take place; Experiment 25 showed that much more carbon dioxide was present in expired air than inspired. In addition to the gases mentioned, water vapour is always present as the result of evaporation from rivers and seas ; the amount varies from day to day according to the weather. Like carbon dioxide, the amount in the air inside buildings depends on the ventilation.

Air is a **mixture** of these various gases, *not* a compound. The composition is not definite, for the amount of the different

gases present varies slightly. The constituents can easily be separated (as was done in the experiments on burning and rusting) and, conversely, if the right amounts of the gases are taken and mixed, a sample of air is obtained without any chemical change taking place. The properties of air are similar to those of the gases from which it is composed and might be predicted from a knowledge of their properties. All the characteristics of composition, separation and properties are typical of any kind of mixture, but not of a compound.

Oxygen. It is well known that doctors use oxygen to sustain life when a person is very ill with some such disease as pneumonia. It is the constituent of the air which is essential for combustion and for the life of men, animals and plants.

When burning and rusting take place, the active portion of the air—the oxygen—is used up, and goes to form compounds with such elements as iron, magnesium and phosphorus. **Priestley** in 1774, when experimenting with a similar compound formed by heating mercury in air, first obtained the gas, oxygen, in a separate state. The substance he used was a red powder, mercuric oxide.

EXPT. 61. **Effect of heating mercuric oxide.** Put a small quantity of mercuric oxide in a hard glass tube and heat it strongly. Place a glowing splint of wood in the tube and see that it relights with a slight pop. Notice the silvery deposit on the cold part of the tube ; rub it with a pencil and see that drops of mercury form as the minute particles run together. Heat red lead also and test the gas given off.

When mercury is heated strongly in air it combines with the oxygen of the air to form mercuric oxide. Conversely when mercuric oxide is heated, it breaks up again into its two constituents, oxygen and mercury. The oxygen is given off, and can be detected by the usual test for the gas—the relighting of a glowing splint. Red lead, when heated, gives off oxygen and turns into a compound of lead and oxygen called litharge ; obviously litharge contains less oxygen than red lead.

Preparation and properties of oxygen. Mercuric oxide is expensive and gives off oxygen somewhat slowly. To obtain a large quantity of oxygen, oxygen mixture is used. This consists of potassium chlorate and manganese dioxide ; the oxygen is obtained from the potassium chlorate, and the manganese dioxide has the curious effect of making the oxygen come off more easily and at a lower temperature, while itself remaining unchanged.

EXPT. 62. **Preparation of oxygen.** Powder some crystals of potassium chlorate and mix with it a small amount of manganese dioxide (about four parts to one). Place the mixture in a hard glass tube, support the tube horizontally and connect it by a delivery tube to a trough of water as shown in Fig. 151. Fill several gas jars

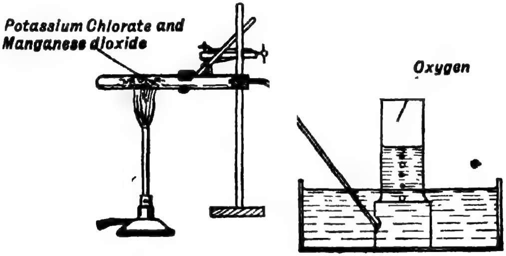


FIG. 151. PREPARATION OF OXYGEN.

opposite

with water and invert them in the trough. Gently warm the tube and when the air has been driven out of the apparatus collect several jars of oxygen by displacement of the water in the jars. Cover the mouths of the jars with a greased glass plate and remove them from the trough. Do not cease to heat the hard glass tube until after the end of the delivery tube is removed from the water.

To examine the properties of oxygen, various substances are heated on a deflagrating spoon till they start to burn ; they are then lowered into a gas jar of oxygen, so that they continue to burn in the gas. Litmus solution is then shaken up in the jar, and if the substance formed by burning dissolves in water, the solution may turn red or blue ; a red colour shows an acid is formed while a blue colour indicates an alkali.

Expt. 63. **Properties of oxygen.** (*a*) **Test the first jar of gas (using one of the last to be collected) for colour, taste and smell. Hold a glowing splint of wood in the gas; it bursts into flame.**

(*b*) Lower a lighted candle on a deflagrating spoon into another jar; it burns with a larger and a brighter flame.

(*c*) Burn a small piece of roll sulphur in one jar; it burns with a bluish flame and a pungent smelling gas is formed. On shaking up with litmus, the gas dissolves to form a red solution.

(*d*) Perform a similar experiment with phosphorus; it burns with a brilliant flame and there are dense white fumes. These dissolve when shaken up with litmus to form a red solution.

(*e*) Attach some strands of fine iron wire to the spoon and heat them to red-heat. Quickly insert them in a jar of oxygen and a "fireworks" effect is produced as the iron burns. The black solid left is insoluble in water and has no effect on litmus.

(*f*) In a similar way, burn a piece of dry charcoal in another jar; it burns brilliantly. Add some lime water to the jar and shake; the lime water turns milky.

(*g*) Quickly lower a piece of burning magnesium ribbon into a jar; it burns with a dazzling brilliance. The white powder formed is slightly soluble in water and turns litmus blue.

(*h*) Burn a piece of sodium in oxygen **(taking care only to handle the sodium with tongs or forceps)**; it burns with a yellow flame. The white solid formed is soluble in water and turns litmus blue.

Oxygen has no colour, taste or smell. Substances burn in it much more brilliantly than in air and some, such as charcoal and iron, which do not burn readily in air, burn vigorously in oxygen.

Oxides. Most elements burn very vigorously in oxygen to form compounds called **oxides.** Some oxides, such as those of carbon and sulphur, are gases; others, like magnesium, iron, phosphorus and sodium, are solids. When they dissolve in water, in some cases an acid solution is formed, and in others an alkaline. Magnesium and sodium are metals, whereas phosphorus, sulphur and carbon are non-metals. It seems, then, that *metallic* oxides, when soluble in water, form **alkalis** and *non-metallic* oxides, when soluble in water, form **acids.** When oxygen was first discovered, it was thought that all acids contained oxygen, but it is now known that some acids are not formed from oxides, and contain no oxygen.

Prevention of rusting. The metal most commonly used in the world to-day is iron and consequently our time is often called the Iron Age. It will be seen in Chapter XV that by various processes the natural iron ore, which chiefly consists of oxides of iron, can be converted into metals of differing strength and hardness and so we have mild steel and hard steel, wrought iron and cast iron. Each of these has its different uses—for knives, scissors, railway lines, gates and a multitude of other objects.

One great disadvantage of iron, however, is the corrosion that occurs when it is exposed to air and water (as was seen in Expts. 55-57). The red powdery substance known as iron rust is an oxide of iron (or more exactly it is partly an oxide, partly a hydroxide) and the formation of it causes much waste, because layers scale off and more metal is exposed to the air until the whole of the metal tends to become corroded. Once a surface has started to rust, the process proceeds more rapidly. It has been seen that the presence of air and of moisture favours rusting, so that the simplest method of preventing it is to keep the air away from the iron surface. This is often done by covering the iron with some material which will protect it from the air. Thus many kitchen and household utensils are covered with **enamel**, a glaze that is put on in a molten state and which solidifies on cooling. Other tin articles used for cooking are really made of sheet iron covered with a thin layer of tin. The substance known as **galvanised iron**, largely used for pails, baths and tanks, consists of iron which has been coated with molten zinc and then left to cool. Unlike enamel, zinc readily dissolves in acids, so that galvanised iron vessels are not suitable for acid foodstuffs.

When tools or utensils made of iron or steel are only used infrequently and need to be stored, they may be kept from rusting by covering them with oil or vaseline. For outdoor purposes, such as railways and water pipes, paint is generally used to preserve the iron.

In recent years, great progress has been made in the manufacture of new kinds of steel by combining small quantities of other metals with it. Thus **stainless steel** containing a small proportion of chromium and nickel is both rustless and stainless, and is now used extensively for cutlery and tableware.

Nitrogen. The nitrogen in the air dilutes the oxygen and so slows down its very active effect. In an atmosphere of pure oxygen a candle would burn away with much brilliance in a few minutes ; in an atmosphere of pure oxygen our lives might be short but fiercely active. Despite the fact that nitrogen is

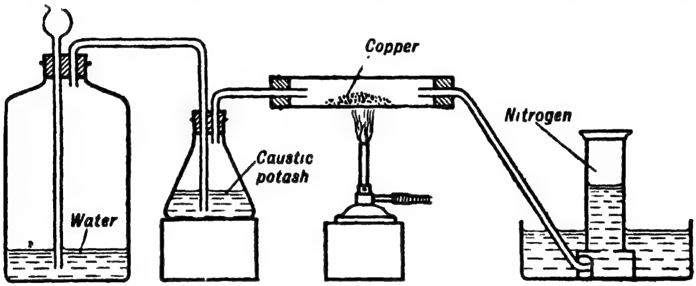


FIG. 152. PREPARATION OF NITROGEN.

so inactive in the ordinary way, it is of vital importance to plant life. The majority of plants cannot make use of the nitrogen in the atmosphere but where it is present in compounds such as nitrates (in compounds it is known as " fixed " nitrogen), it can easily be absorbed from the soil.

In Expts. 58 and 60, the gas obtained was almost entirely nitrogen. Any experiment in which oxygen is removed from a given volume of air is a means of obtaining nitrogen in a fairly pure state.

A better way of removing the oxygen is by passing air slowly over heated copper filings (Fig. 152). As water is poured into the aspirator, air is forced out, so that it passes through the smaller bottle containing caustic potash ; this absorbs the

carbon dioxide. The air then passes over the heated copper filings and these combine with the oxygen in it to form a black oxide of copper. Nitrogen is thus collected in the gas jar. It is a colourless, odourless, tasteless gas, very slightly soluble in water. A lighted taper lowered into it goes out immediately. Although it does not support combustion or sustain life, it is not in itself poisonous, or obviously we should not breathe it with impunity. It does not make lime water milky (this is a way of distinguishing it from carbon dioxide), and it combines directly with very few substances.

Carbon dioxide. When carbon (or charcoal) is burnt in a jar of oxygen, the gas formed turns lime water milky. This gas, carbon dioxide, is only present in a small quantity in the air, but it is continually being produced by the respiration of plants and animals and by the burning of different fuels. So when coal, which consists chiefly of carbon, is burnt, carbon dioxide is formed and a great deal of heat is given out. Our flesh contains compounds of carbon and when these are slowly oxidised by the oxygen of the air we breathe in, carbon dioxide is formed, and we derive heat and energy from the process.

With carbon dioxide continually being formed in this way it might be expected that the percentage present in the air would increase, but actually such is not the case. One reason is that carbon dioxide is the chief food of plants ; they take it in and use it for the manufacture of their food. Another reason is that the oceans help to regulate the amount of carbon dioxide present in the atmosphere ; the gas is soluble in water, and if too much is present in the air, the sea water dissolves more, or if there is too little, the sea gives up some to the air.

EXPT. 64. **Use of carbon dioxide by plants.** Take some fresh watercress and place it in a beaker of soda water (or water saturated with carbon dioxide). Over the plant place a funnel and a test tube full of the same water (Fig. 153) ; the funnel should be supported on three wires so that it does not touch the bottom of the

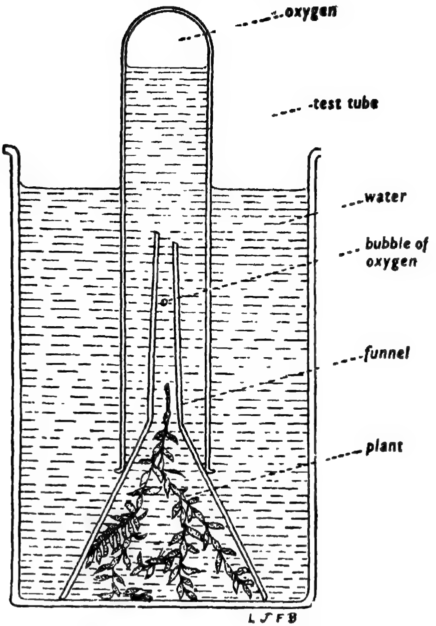


FIG. 153. IN THE SUNLIGHT THE WATERCRESS GIVES OFF OXYGEN.

beaker. Leave the apparatus in bright sunlight for some hours. Bubbles of gas will be seen to rise from the leaves and collect in the test tube. Remove the test tube and test the gas with a glowing splint. Repeat the experiment, but keep the apparatus in the dark.

Plants breathe in oxygen and give out carbon dioxide just like animals, but in addition, they obtain their food by absorbing carbon dioxide and giving out oxygen, as in the experiment. This latter process only takes place in the presence of sunlight, so that green plants only feed in the daytime. More will be said about the respiration and nutrition of plants and animals in Chapter XVII.

EXPT. 65. **Preparation of carbon dioxide.** Fit up a flask with a cork, thistle funnel and delivery tube as shown in Fig. 154.

Place some pieces of marble in the flask and pour hydrochloric acid down the funnel until the acid covers the bottom of the funnel. Collect the gas by downward displacement, that is, by letting the gas pass down the delivery tube into the gas jar, where, being heavier than the air, it will displace it and fill the gas jar. To test if a gas jar is full, put a lighted taper just inside the mouth ; it goes out when the gas fills the jar. Collect four jars of the gas. Let the gas bubble through a beaker of water ; taste the water.

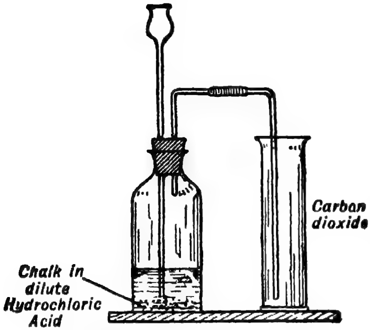


FIG. 154. PREPARATION OF CARBON DIOXIDE.

EXPT. 66. **Properties of carbon dioxide.** (*a*) Examine one jar for colour, taste and smell. Verify also that a lighted taper goes out when plunged right into it.

(*b*) Pour the gas from one jar down into another (Fig. 155). Test for its presence in the two jars with a lighted taper.

(*c*) Pour some water coloured with litmus solution into a jar of the gas. Shake it up and notice the colour change to red.

(*d*) Pour some lime water into a jar and shake it up well. Filter the milky solution and examine the white substance on the filter paper. Put some in a test tube, add hydrochloric acid, and see if the gas given off can be poured down into some clear lime water in a second test tube.

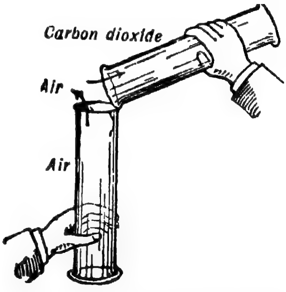


FIG. 155. CARBON DIOXIDE MAY BE POURED FROM ONE JAR INTO ANOTHER.

Carbon dioxide can be prepared by the action of dilute hydrochloric acid on marble or chalk. The gas has no colour or smell, and does not support combustion. It can be poured downward because it is heavier than air. It gives an acid taste to water, and dissolves in it to form an acid solution. The usual test for it is that of turning lime water milky ; the milkiness is due

to the formation of particles of chalk which are in suspension in the lime water.

Water vapour. The water vapour in the air of a room is obvious when some of it condenses as drops of water on a cold window-pane. Out of doors, clouds, rain, mist, fog and dew all consist of particles of water formed by the condensation of the water vapour in the atmosphere and when it is sufficiently cold for such water to freeze, snow, hail and hoar-frost result.

Dew. Warm air can absorb more water vapour than cold, so that when warm air cools it cannot retain all its moisture and there is a tendency for some to condense. Thus when the air becomes cooled at night, under certain conditions, some of its moisture will be deposited as **dew.** The most favourable conditions are (1) when there is a little wind, so that the cold layer of air near the ground is stationary; and (2) when the sky is clear, so that the earth can radiate its heat freely without the waves of radiant heat being reflected back by the clouds; the temperature of the air and the earth near it is then considerably lowered. Certain conditions, then, are necessary for dew, but at any time dew can be obtained from the air by cooling it. The temperature at which the air deposits its moisture in the form of dew is the **dew-point.**

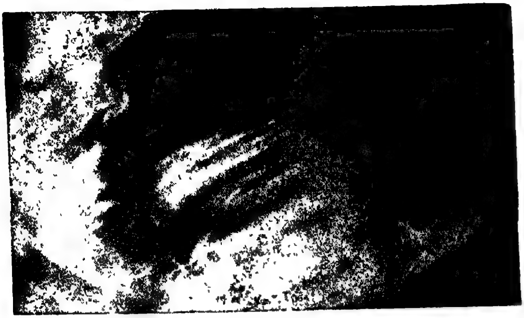
EXPT. 67. **Determination of dew-point.** Half fill a brightly polished metal vessel with water. Add ammonium chloride or small lumps of ice, stirring gently with a thermometer and watching for dew to appear on the outside of the vessel. Care must be taken not to get too near or to breathe on the surface; it is better to interpose a sheet of glass between the vessel and the face. At the first sign of dew, read the thermometer. Remove the surplus ice, and let the water warm up until the dew disappears again. Take the mean of the two thermometer readings as the dew-point.

The dew-point varies from day to day. On a cold winter's day, the amount of water vapour in the air may very nearly saturate it, and it may only need to be cooled a few degrees

before dew-point is reached. On a warm, dry day a great deal of cooling may be necessary.

Clouds. The air is continually moving and generally the tendency is for streams of air to move upwards, particularly in regions of low barometric pressure. Such upward currents of air become cooled on reaching higher layers of the atmosphere until eventually the temperature of the air falls below its dew-point, and the water vapour condenses to form minute particles of water. At first these are too small to be visible, but as they are carried upwards they increase in size till they become large enough to be visible; the level at which this occurs is cloud-level and the visible particles of water form the clouds. The cloud-level is, of course, not constant, but when the water particles in a cloud are sufficiently cooled by a cold current of air or by being carried higher up, they collect together and form drops which fall as rain. If the condensation of the water vapour occurs at a temperature below 0° C., snow falls instead of rain.

The four chief types of clouds are cirrus, cumulus, stratus and nimbus clouds (Fig. 156). Some clouds have characteristics of two types, and so are named cirro-cumulus, cumulo-nimbus and so on. Cirrus clouds are white streaky wisps very high in the sky; actually they are from five to ten miles above the earth, and at that height the water is frozen, so that they consist of minute particles of ice. Cumulus clouds are the big white fleecy ones that look like lumps of wool; they are often only a mile above the earth. One often sees in a blue sky, cirrus clouds very high up and apparently stationary, with fluffy cumulus ones moving rapidly across lower down. A mackerel sky is like both types, and so is termed cirro-cumulus. Stratus clouds are horizontal flat stretches of cloud, particularly noticeable at sunset; they are quite low and consist of banks of lifted fog. Nimbus clouds are rain clouds; they are dark and shapeless with uneven edges and frequently they are so low that on a hill or mountain it is possible to be in them or above them.



'MARES TAILS'–CIRRUS

CUMULUS

CUMULO-NIMBUS

FIG. 156. SOME TYPES OF CLOUDS.
(From photographs by M. G. A. Clarke, Aberdeen.)

Humidity. The dampness of the air is important with regard to its effect on health and industry. Its effect on health has been considered in connection with ventilation, and it is also well known that a climate that is very damp as well as very hot is far more trying than a hot, dry one. Industries, such as cotton manufacture, require a certain humidity of the air. In a house, the rate at which wet floors or wet clothes dry depends on how quickly the water evaporates, and this is determined by the dampness, or humidity, of the air. The humidity, however, depends not only on the amount of water vapour actually present, but also on the amount that would be required to saturate it; if the amount present is nearly great enough to saturate the air, the humidity is very high. For meteorological purposes, the relative humidity is determined.

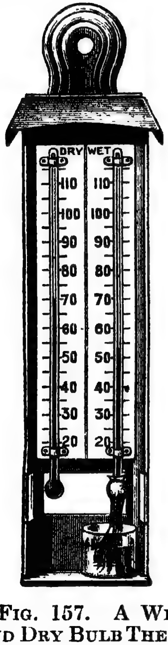


FIG. 157. A WET AND DRY BULB THERMOMETER.

$$\text{Relative humidity} = \frac{\text{Amount of water vapour present in the air at a given temperature}}{\text{Amount of water vapour that would saturate it at the same temperature}}.$$

Wet and dry bulb thermometer. The usual instrument for determining the relative humidity of the air is the wet and dry bulb thermometer. It consists of two precisely similar Fahrenheit thermometers (Fig. 157), the bulb of one being surrounded by a muslin cover from which strands of cotton dip into a vessel of water. Thus the muslin is kept wet by capillarity, and evaporation is continually taking place from the muslin. In this way the wet bulb is cooled and always registers a lower temperature than the dry one. The difference of the readings of the two

thermometers is greater on a dry day because evaporation is more rapid and the cooling effect is more pronounced. A value for the relative humidity of the air can be obtained from tables when the wet bulb reading and the difference between the two readings is known.

EXPT. 68. **Variation in humidity of the air.** Read the wet and dry bulb thermometer every day for a fortnight. Plot a graph of the readings. Notice how the difference varies from day to day, and decide from the graph which day would have been the best for drying clothes.

CHAPTER XIII

WATER

Properties of water. Water is one of the most common and most necessary substances in the world around us. It has been seen that the way in which it is supplied to our homes is the result of its property of exerting pressure and tending to find its own level. It is known also that 1 c.c. of water at 4° C. weighs 1 gm., this actually being the origin of the metric unit of weight. Water is familiar in all three states, solid, liquid and gas. Below 0° C. it exists as ice; at 0° C. it melts to form liquid water; at 100° C. the liquid is converted into steam. Steam is pure water and by the process of distillation, steam can be condensed to form the pure liquid.

In the analysis of distilled water by electrolysis, described in Chapter IX, it was shown that pure water is a compound of the elements hydrogen and oxygen. Actually natural water, such as rain water, river water and sea water, contains a variety of other substances as well, but it is simpler to begin our study of water by considering first the way in which it is fundamentally composed of these two elements.

Hydrogen. The most convenient method of preparing hydrogen in the laboratory is not by electrolysis, but by the action of dilute sulphuric acid on granulated zinc.

Expt. 69. **Preparation and properties of hydrogen.** (*a*) Fit up the apparatus of Fig. 158. Care should be taken that a tightly fitting rubber cork is used in the flask and that the tube and funnel fit tightly into the stopper. Place some granulated zinc into the flask, fit the stopper in firmly and pour dilute sulphuric acid down

the funnel until the surface of the acid is well above the bottom of the funnel. Collect several jars of hydrogen.

(*b*) Remove the trough of water from the apparatus and by means of rubber tubing, connect the stem end of a clay pipe to the end of the delivery tube. Dip the pipe into a dish of soap solution, increase the pressure of the hydrogen issuing from the delivery tube by placing a hand over the thistle funnel and so obtain a soap bubble filled with hydrogen. Jerk it from the pipe, and note that the bubble floats up to the ceiling; this shows that hydrogen is lighter than air.

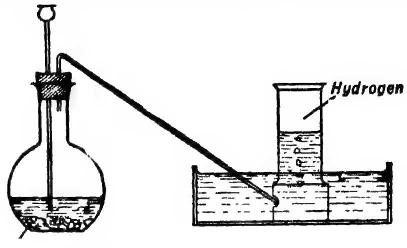


FIG 158. PREPARATION OF HYDROGEN.

(*c*) Hold the first jar of hydrogen collected mouth downwards and apply a lighted taper to the gas. There will be a slight explosion because some air was mixed with hydrogen. Now take the third jar collected and apply a light to it; the gas burns with a blue flame. Thrust the lighted taper up into the jar gas; the taper goes out. Notice the film of moisture formed on the sides of the jar.

Hydrogen, then, is a colourless, odourless gas. Its lack of odour is apparent during the experiments, when a quantity of gas escapes into the room. It is extremely light and is, in fact, the lightest substance known. In the past it has been used a great deal for filling balloons and airships, but now helium, which is almost as light and is non-inflammable, is being used in its stead. Hydrogen mixed with air forms a highly explosive mixture, but pure hydrogen burns quietly with a blue flame.

Burning of hydrogen. When hydrogen is burnt in a gas jar a film of moisture is formed on the sides of the jar. This effect may be investigated more completely by letting the flame of burning hydrogen impinge on a cold surface, so that the product of burning is condensed and collected.

Hydrogen is prepared as before and passes through two tubes containing calcium chloride; the latter serve to absorb the

moisture from the gas (Fig. 159). Before lighting the jet of gas issuing from the delivery tube, careful tests must be made to ensure the apparatus is air-tight and no air is mixed with the hydrogen ; otherwise a dangerous explosion may result. Test tubes are held over the delivery tube, and then removed to a flame a little distance away ; if the gas in them explodes, the apparatus needs further adjustment, but if it burns quietly, the hydrogen is pure and the jet may safely be lighted. The burning hydrogen strikes the surface of a vessel through which a

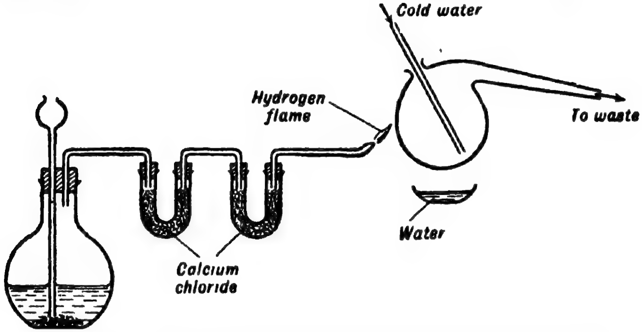


FIG. 159. WATER PRODUCED WHEN HYDROGEN BURNS.

continuous stream of cold water is flowing ; moisture forms and drops into the dish below. Tests of this liquid, such as estimates of its density and its freezing and boiling points, show that it is water.

When hydrogen burns in air, water is formed. The process is similar to that when a metal like magnesium burns in air and an oxide of the metal is formed. Water is actually an **oxide of hydrogen.**

This process of building up the compound, water, from the two elements oxygen and hydrogen, is termed the **synthesis** of water. It is obviously the reverse process from that of analysis, where the water is broken up into the two gases. Both analysis and synthesis show definitely that water is a compound of oxygen and hydrogen.

Composition of water by weight. The exact weight of each of the elements present may be found by the **reduction** of copper oxide, that is, by the removal of the oxygen from the oxide, so that the metal is left.

Some dry black copper oxide is placed in a " boat " and weighed. It is then placed in a piece of hard glass tubing and connected with the apparatus for generating hydrogen (Fig. 160). At the other end of the hard glass tubing are attached two U-tubes of calcium chloride, which have previously been weighed. Hydrogen is passed slowly over the copper oxide, and when tests have been made, as in the previous experiment, to ensure

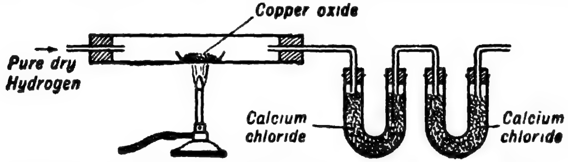


FIG. 160. THE COMPOSITION OF WATER BY WEIGHT.

hat pure hydrogen is issuing from the end of the apparatus, the oxide is heated. The end of the hard glass tube should also be heated to ensure that any condensed water is carried over into the weighed U-tubes.

When the copper oxide is reduced, that is, converted to metallic copper, heating is discontinued, but the hydrogen is allowed to flow until the copper is cold. Decrease in weight of the " boat " containing copper oxide is noted, and the increase in weight of the calcium chloride tubes. The first value gives the amount of oxygen used, and the latter value the amount of water formed. From the difference of these two amounts, the weight of hydrogen used can be calculated.

Such an experiment shows that water is composed of one part by weight of hydrogen to eight parts of oxygen. The composition of water indicated by electrolysis agrees with this when it is realised that oxygen is sixteen times as heavy as hydrogen. When two volumes of hydrogen combine with one volume of

oxygen, the *weight* of hydrogen used is one-eighth that of oxygen.

Natural waters. Water made by the synthesis of oxygen and hydrogen or pure distilled water leaves no residue if evaporated to dryness, because the two elements are its only constituents. Natural water, however, varies considerably both in appearance and taste, because it contains not only dissolved air as was described on page 167, but also various dissolved solids.

EXPT. 70. **Evaporation of rain water, tap water and sea water.** Into weighed evaporating dishes measure 100 c.c. each of clean rain water, tap water and sea water. Evaporate to dryness. When nearly all the water has disappeared heat carefully to avoid spurting. Finally re-weigh and compare the amount of dissolved solid in 100 c.c. of each kind of water. Taste the residue left from the sea water.

EXPT. 71. **Solubility of soil in rain water.** Shake up a few grains of fine soil with 100 c.c. of rain water. Allow the solid matter to settle, and note that some remains in suspension. Pour off the liquid and filter it. Evaporate the filtrate to dryness and see if there is an appreciable residue.

There is generally about 3·5 gm. of dissolved solids in 100 gm. of sea water, most of it consisting of common salt. In tap water, which is sometimes river water, sometimes a mixture of river and well water, there are only a few decigrams of dissolved solid, the amount varying according to the district. Water from the Thames contains 0·028 gm. in 100 gm. of water, while that from the Trent contains as much as 0·071 gm.; some river water contains less than 0·010 gm. Rain water yields only a negligible residue and, if clean, is the purest form of natural water. This is because, like distilled water, it is formed by the condensation of pure water vapour; in its passage through the air as rain, it dissolves some air and a very small quantity of solid matter.

When rain falls on the earth, some water drains away on the surface and joins streams and rivers, some is retained as

moisture in the soil, while the rest sinks down until it reaches a non-porous stratum. Thence it may find its way out to the side of a slope and form a spring, or it may remain until a well is sunk to it. In either case, mineral salts from the soil become dissolved in it. At spas such as Buxton and Bath, the water is sought after because the mineral salts in it have medicinal properties. When water flows as a river, there may be solid matter in suspension in it as well as dissolved solids, because mineral matter and animal and vegetable remains are caught up from the soil but do not dissolve.

River water. Air in the top layer of soil is particularly rich in the carbon dioxide produced by the decay of plants. Consequently water, after reaching the earth, gains carbon dioxide in addition to that dissolved from the air when passing through it as rain. Although the total amount of carbon dioxide present in water is quite small, it has a pronounced effect on the solvent power of the water, particularly in regions such as the North and South Downs or the Pennines, where rivers flow over chalk or limestone.

Expt. 72. **Solubility of chalk in (a) distilled water, (b) water saturated with carbon dioxide.** Set up the apparatus for preparing carbon dioxide and bubble the gas through 100 c.c. of distilled water for ten minutes. Measure out 100 c.c. of ordinary distilled water. To each sample of water, add 1 gm. of finely powdered chalk, shake thoroughly, filter to remove the undissolved chalk and evaporate to dryness. Compare the amounts of chalk dissolved in the two cases.

It has been seen in an earlier chapter that carbon dioxide solution contains a weak acid, which is carbonic acid. This acid is a very unstable compound, and readily splits up again into the carbon dioxide and water from which it is formed. Its presence, however, increases the solubility of chalk to a marked degree. When chalk is shaken up in water saturated with carbon dioxide, the clear solution obtained after filtering is really a specimen of hard water. Chalk (or calcium carbonate),

when it dissolves in water containing carbon dioxide, becomes changed to **calcium bicarbonate**, a substance soluble in water and the chief cause of **hardness** of water.

Hardness of water. When washing, it is always obvious if the water is *hard* or *soft*, because if it is hard, much soap has to be used to obtain a lather, and a greyish scum is formed on the water. What is actually happening is that the soap has to combine with the dissolved solids in the water before it is free to form a lather. With rain water, which contains no such dissolved solid, a lather is obtained immediately.

Hardness of water is most frequently due to calcium bicarbonate and calcium sulphate, but magnesium bicarbonate and magnesium sulphate and a little sodium chloride are often present also. When soap (sodium stearate) is added to hard water the calcium bicarbonate will not lather with the soap, and a chemical reaction takes place between them until all the calcium bicarbonate is used up ; the soap is then free to form a lather. The effect may be represented thus : $NaHCO_3$

$Na + CaHCO_3 \rightarrow Ca$

sodium stearate (Soap)	+	calcium bicarbonate	=	calcium stearate (Scum)	+	sodium bicarbonate.

$Na + CaHCO_3$ $Ca + NaHCO_3$

When soap lathers in water, the soapy solution has the power of dispersing grease and loosening particles of dirt that may be held in the grease. In the case of hard water, however, the soap has first to combine with the calcium bicarbonate in the water to form a scum of calcium stearate, and these insoluble particles tend to stick to the grease and dirt. For this reason clothes washed in hard water must be thoroughly rinsed, so that all such solid matter is removed.

EXPT. 73. **Comparison of the hardness of rain water, tap water, boiled tap water.** Make a soap solution by dissolving shredded soap in methylated spirit, and fill a burette with it. Measure 50 c.c. of water with a pipette and pour it into a small flask. Add 1 c.c. of the soap solution to the water (Fig. 161), cork the flask tightly and shake it vigorously. If a *permanent* lather (that is, one

that lasts five minutes without the bubbles breaking) is not obtained continue to add the soap solution 1 c.c. at a time. Compare the amounts of soap solution needed to make a permanent lather with each kind of water.

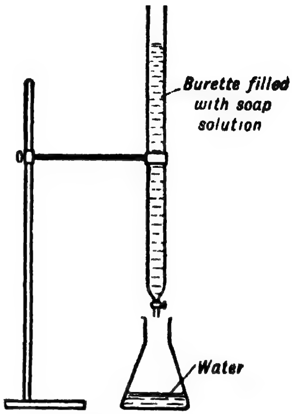


FIG. 161. COMPARISON OF THE HARDNESS OF DIFFERENT WATERS.

Temporary and permanent hardness. Boiled tap water is found to be less hard than ordinary tap water, so the process of boiling seems to remove some of the hardness. The kind of hardness that can be removed by boiling is termed temporary hardness, and that remaining is called permanent hardness. An experiment may explain this difference in hardness.

EXPT. 74. **Effect of boiling water containing carbon dioxide.** (*a*) Put a little blue litmus solution in a beaker of distilled water, and bubble carbon dioxide through the water until there is a distinct change of colour. Boil this reddish solution and note any further colour change.

(*b*) Sprinkle a little powdered chalk in a similar beaker of distilled water, and again bubble carbon dioxide through the water until the chalk dissolves and a clear solution is left; this is artificially prepared hard water. Now boil the solution for some minutes and note the effect.

The first solution loses its acid properties when boiled, because the unstable carbonic acid is broken up into water and carbon dioxide again, and the gas is driven out of the water. Similarly, in the second solution, the dissolved calcium bicarbonate causing the hard water breaks up into chalk and carbon dioxide again when the liquid is boiled, the carbon dioxide being driven off, and the insoluble chalk remaining. Hence boiling removes part of the hardness of water, because all that due to chalk is removed by the chalk being thrown out of solution. Temporary

hardness is caused chiefly by chalk and calcium carbonate, permanent hardness by calcium sulphate, the latter substance remaining dissolved in the water however much it is boiled.

Thus the " fur " in a kettle is calcium carbonate that is thrown out of solution when hard water is boiled. Sometimes it has a brownish tinge because of the presence of a little iron carbonate also. The formation of layers of such " fur " in hot water pipes and boilers is a source of great inconvenience because it tends to prevent the water becoming thoroughly heated and may make a boiler crack. Fig. 162 shows the extent to which a pipe may become blocked when very hard water is used.

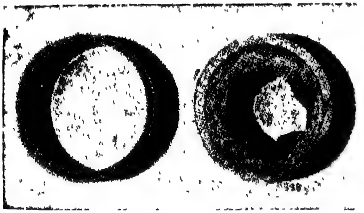


FIG. 162. THE EXTENT TO WHICH A PIPE MAY BECOME BLOCKED BY "FUR."

Methods of softening water. For household purposes it is advisable to soften very hard water, both for economy and convenience. Less fuel is required for heating if boilers are not coated with " fur " as just described ; moreover less soap, soda and tea need to be used if the water is fairly soft. Washing processes can be carried out more conveniently because there is less formation of scum. Small quantities of water may be softened by simple household methods, but where possible, it is better to have some type of water softener fitted to the main supply pipe, so that all the water passing into the house is softened.

EXPT. 75. **Comparison of the softening effect of (a) boiling, (b) adding lime, (c) boiling and adding washing soda.** (*a*) Boil 250 c.c. of water for fifteen minutes, and leave it to cool so that all suspended particles settle. As in Expt. 74 compare the hardness of 50 c.c. of ordinary tap water and 50 c.c. of this boiled tap water.

(*b*) To 100 c.c. of ordinary tap water, add lime water until the milkiness produced seems to have reached a maximum. Filter a little of the solution into a test tube, and see if further milkiness is

produced when lime water is added. If this is found to be the case, add more lime water to the bulk of the hard water and re-test. It is important that there should not be an excess of lime water, because such adds to the hardness of the water. When the lime water has produced as much milkiness as possible, filter and test the hardness of 50 c.c. of the solution.

(c) In 100 c.c. of the boiled water, dissolve ½ gm. of washing soda, filter and test the hardness of 50 c.c. of the solution.

The various methods of softening water either cause calcium bicarbonate and calcium sulphate to be thrown out of solution as the insoluble carbonate, or else they convert these substances into sodium compounds which have no hardening effect. The best simple method of obtaining soft water for domestic purposes is by boiling and adding washing soda, both temporary and permanent hardness being removed by these means. Lime and the process of boiling remove temporary hardness only.

The addition of lime is the method used on a large scale in waterworks to remove temporary hardness from the water supplied by the town mains. By **Clark's process**, as it is called, thousands of gallons of water can quickly be softened. The effect may be represented thus : $CaCO_3 + H_2O$

$2HCO_3$ calcium bicarbonate + slaked lime = calcium carbonate + water.

The lime combines with carbon dioxide from the bicarbonate to form calcium carbonate, and this chalk together with that causing hardness appears as a milkiness in the water and is allowed to settle. Exactly the right amount of lime needed for a certain type of water must be estimated, for any excess may itself make the water hard. For a town supply, water must not be made too soft, because soft water dissolves lead from lead pipes, and lead poisoning may result if such water is drunk habitually. Waterworks, therefore, remove some, but not all, of the hardness, the amount left varying considerably from place to place.

Water softeners. A common form of household water softener is the permutit one (Fig. 163). Permutit is the trade name given to a compound of sodium aluminium silicate. This substance reacts with both calcium bicarbonate and calcium sulphate, so that it has an effect on both temporary and

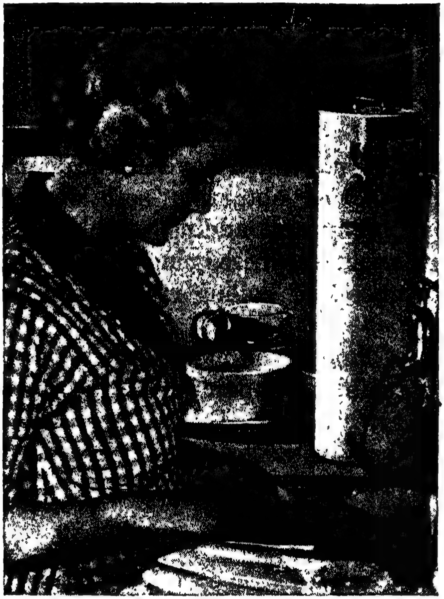


FIG. 163. A "PERMUTIT" WATER SOFTENER IN USE IN A KITCHEN.
(By courtesy of United Water Softeners, Ltd.)

permanent hardness, and softens the water by removing the calcium salts from it. The sodium aluminium silicate is contained in a tube through which the hard water flows, and it combines with the calcium bicarbonate and the calcium sulphate to form calcium aluminium silicate, a substance which is insoluble in water and which remains in the tube. In this way, the calcium salts causing hardness are converted into an insoluble compound which is deposited.

To convert this insoluble calcium aluminium silicate back into permutit again a strong solution of common salt is poured through the tube.

Stalactites and stalagmites. A phenomenon occurring in nature and resulting from the presence of calcium bicarbonate in water is the formation of stalactites and stalagmites (Fig. 164). As water drips from the roof of caves, the calcium bicarbonate in it slowly decomposes as the water evaporates, and calcium carbonate is formed. That deposited on the roof forms hanging parts known as stalactites, while that resulting from the drops of water that fall on the floor, causes stalagmites

FIG. 164. STALACTITES AND STALAGMITES IN COX'S CAVE, CHEDDAR.

The central column is 3 feet, 4½ inches high.

(Reproduced by courtesy of the Proprietors of Cox's Cave, Cheddar.)

CHAPTER XIV

CHEMICAL LAWS. SYMBOLS. FORMULAE. EQUATIONS

Nature of matter. In the last two chapters, much has been learnt about the two most common substances in the world around us, air and water. Before going on to study the nature of the many other substances that are familiar to us, it is well to know something of the way in which all of them are built. In Chapters IX and X, mention has been made of **atoms** and of their electrical constituents. Even two thousand years ago certain Greeks believed that matter must be made up of atoms, the tiniest particles into which a substance could possibly be divided without losing its identity. The revival of this Greek idea by **John Dalton** (1766-1844) (Fig. 165), led to tremendous advances in our theories about the nature of matter until now, in the twentieth century, it is known that atoms consist of nuclei around which smaller particles revolve, and that the nucleus is the part of them which tends to remain the same in chemical action. Even the nucleus itself is split in the phenomenon known as atomic or nuclear fission, but this is a physical and not a chemical process.

Atoms. Nowadays we talk glibly about atomic energy and refer to atoms as if we could pick them up and count them like marbles, but actually they are infinitesimally too small ever to be seen, and it has been said that there are as many atoms in a thimbleful of water as there are thimblefuls in the Atlantic Ocean.

All atoms are not alike. They vary according to the amount of positive charge on the nucleus and the number of electrons round it, the simplest atom being that of hydrogen. In estimating their weight, therefore, the value for the **atomic weight**

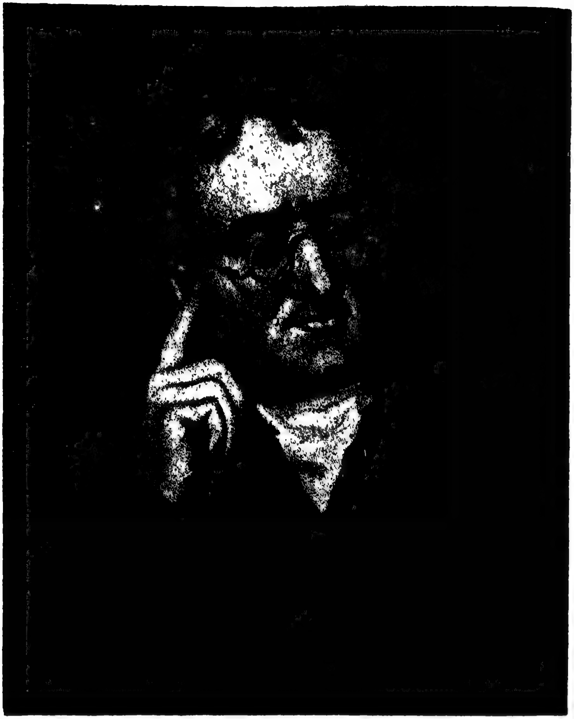


FIG. 165. JOHN DALTON 1766–1844.

of hydrogen is taken as 1 and the others are compared with it; thus the atom of oxygen is sixteen times as heavy as that of hydrogen and so has an atomic weight of 16. Such values are simpler than those that would be obtained if the actual weight in grams in the atom were used, for that of hydrogen is $1 \cdot 66 \times 10^{-24}$ gm., that is, a number with twenty-three noughts between the decimal point and the figures.

In an **element**, the atoms are all of the **same** kind so there are as many different kinds of atoms as there are of elements—ninety-two.

Molecules. Atoms, however, do not generally exist alone, and *the smallest particle of an element or compound capable of existing alone* is called a **molecule.** While an element is made up of molecules containing atoms only of one kind, a *compound* consists of molecules containing two or more different kinds of atoms. Thus in Expt. 49 the compound of iron and sulphur formed from the two elements must have consisted of molecules containing both iron and sulphur atoms. In the *mixture* of iron and sulphur, however, molecules of iron and molecules of sulphur were mixed together, but they kept their identity, and no reaction took place between their respective atoms. When substances react together chemically, molecules of the different substances may be broken up and changes take place in the arrangement of their atoms, but *an atom is the smallest particle of an element which can enter into a compound.* It will be seen that often where pairs and groups of different atoms make up the molecules of compounds, chemical reaction causes them to change their partners. Examples of this will be found in the chapters that follow.

The indestructibility of matter. From experiments chemists have discovered that chemical action between substances takes place according to certain rules or laws. One fundamental law is that, however great the changes that take place in the composition and weight of the various substances used in laboratory experiments or in everyday life, *no matter can ever be destroyed.* This is the **law of the indestructibility of matter,** and it is comparable with the similar fact about energy mentioned at the end of Chapter II. Sometimes matter may seem to disappear, as, for example, when a candle burns away and part of the actual wax candle vanishes. But if the water and carbon dioxide, which are the products of burning, are collected by chemical means, they are found only to equal in weight the wax and the air used by the candle in burning. Wax and air, disappear, but equal amounts of water and carbon dioxide take their place. It is the same with any

chemical change; the products of the change are equal in weight to the substances taking part in it, and the total amount of matter in the world always remains unchanged.

Law of definite proportions. Another important fact about chemical action is that when substances combine to form a compound, it is always a definite proportion of each by weight that combines. So in Expt. 59 when magnesium ribbon was heated, the same proportional increase in weight was found by different experiments, although all had not used the same quantity of magnesium. The increase was due to the oxygen from the air that had combined with the magnesium to form the white powder, magnesium oxide. This compound then must always be formed from definite proportions of the two elements, magnesium and oxygen, and whether a milligram or a kilogram of it is made, there must always be the same proportion of magnesium and oxygen in the compound. Similarly when hydrogen burns in air to form water, a certain definite proportion of hydrogen and oxygen from the air combine to form the compound; it was seen on page 195 that the relative amounts are one part by weight of hydrogen to eight parts by weight of oxygen. A variety of other experiments would all illustrate this same fact. It seems then, that there is a law of chemical combination that definite weights of substances always take place in a chemical reaction and *that a chemical compound always contains the same elements united in the same proportion by weight.*

Chemical symbols. In order to refer to chemical changes briefly and in a condensed fashion, chemical symbols and formulae are used. Thus to represent *one atom* of an element, the chemist writes its initial letter as a capital. So H stands for one atom of hydrogen, O for one atom of oxygen, N for one atom of nitrogen. Since the name of more than one element may begin with the same letter a second letter has sometimes to be used; thus C stands for an atom of carbon and Cl for one of chlorine. For a few elements the symbols are derived from their Latin or Latinised names; for example K for potassium from the

Latin name kalium, Na for sodium from natrium, and Cu for copper from cuprium.

It is important to remember that the symbol represents one atom of an element and not just any quantity. Furthermore, since an atom has a certain atomic weight, it indicates what weights of different elements are present. Thus an O and an H representing one atom of oxygen and one of hydrogen respectively also indicate sixteen parts by weight of oxygen to one part by weight of hydrogen.

If two or more atoms of a particular kind are present, figures are used to indicate their number. When they are joined together to form a molecule, a small figure is placed after the symbol; thus H_2 stands for a molecule of hydrogen and O_2 for a molecule of oxygen, since the atoms of hydrogen and oxygen each go about in pairs. Similarly P_4 represents a molecule of phosphorus consisting of four phosphorus atoms. If several atoms of an element are not joined together to constitute a molecule, we may put a figure in front of the symbol; thus 3H means three atoms of hydrogen, apart from their place in the molecule. But $3H_2$ indicates three hydrogen *molecules*, that is, six hydrogen atoms in all, grouped in three molecules or groups, each containing two atoms.

Formulae of compounds. The formulae of compounds is more complicated, because more has to be known about the grouping of the atoms of different elements to form the molecule. Before this could be achieved two chemists had to carry out experiments, which developed further the atomic theory suggested by Dalton. In 1808 a Frenchman, **Gay-Lussac** (1778-1850), showed that *gases combine in simple proportions by volume,* conditions of temperature and pressure remaining the same. Thus two volumes of hydrogen combine with one volume of oxygen to form two volumes of steam. To explain this fact an Italian, **Avogadro** (1776-1856) brought forward his hypothesis that *equal volumes of all gases, under similar conditions of temperature and pressure, contain equal numbers of*

molecules. On this theory the two volumes of hydrogen contain twice as many molecules as the one volume of oxygen. In the chemical change that takes place for the formation of steam, two molecules of hydrogen must combine with one molecule of oxygen to form two molecules of steam, if Avogadro's idea is correct. Fig. 166 shows how this can be so. Each volume

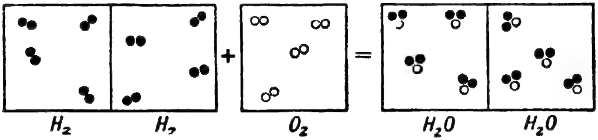


FIG. 166. COMBINATION OF HYDROGEN AND OXYGEN.

of the gases, for the purposes of the diagram, is represented as containing four molecules, it being remembered that the molecules of hydrogen and oxygen each consist of a pair of atoms. When the change takes place the oxygen molecule breaks up and each oxygen atom is partnered by two hydrogen atoms, so that the molecules of steam each consist of two atoms of hydrogen and one atom of oxygen.

If then, compounds are represented by symbols in a similar way to elements, the symbol H_2O represents one molecule of water, the molecule being made up of two hydrogen atoms and one oxygen. Since the oxygen atom is sixteen times as heavy as the hydrogen one, it is obvious that there must be eight parts by weight of oxygen to one part by weight of hydrogen in the compound; this was demonstrated by the experiment of page 195. Other simple formulae of compounds are CO_2 for a molecule of carbon dioxide consisting of one atom of carbon and two of oxygen, CuO for a molecule of copper oxide, consisting of one atom of copper and one of oxygen, NaCl for a molecule of common salt consisting of one atom of sodium and one of chlorine.

Chemical equations. With our knowledge of atoms, it seems then that any chemical reaction really consists in a rearrange-

ment of the atoms of the molecules of the substances taking part. Since matter can never be destroyed, there must be as many atoms at the end as at the beginning, however much their arrangement has been altered. To show concisely the way in which substances behave, chemical equations are written to represent any reaction, with the substances taking part in the change on the left-hand side, and the new ones resulting from it on the right-hand side. The equality sign between the two sides of the equations only refers to weight. As has already been pointed out, the total number of atoms remains unchanged and the total weight of the substances on the left-hand side must be equal to the total weight of those on the right-hand side.

So when carbon is burnt in a jar of oxygen,

$$\underset{\text{carbon}}{C} + \underset{\text{oxygen}}{O_2} = \underset{\text{carbon dioxide}}{CO_2}.$$

Or when hydrogen is passed over heated copper oxide,

$$\underset{\text{copper oxide}}{CuO} + \underset{\text{hydrogen}}{H_2} = \underset{\text{water}}{H_2O} + \underset{\text{copper}}{Cu}.$$

More examples of equations will be given in later chapters.

When equations like this are known as well as the atomic weights of the elements, calculations can be made about the weights of the substances reacting together.

CHAPTER XV

METALS AND ORES. IRON AND STEEL. COAL AND COAL GAS. OILS. LIMESTONE. CLAYS. SAND. GLASS

The substance of the earth. During the time man has lived on the earth he has gradually made more and more use of the substances he has found in the earth's crust. As his knowledge of chemistry has increased, he has found better methods of obtaining them in the form most useful for his everyday life. In this way, metals and metallic ores, coal, oils, chalk and limestone have all become of the utmost value to him.

Properties of metals. Every day we use objects like coins, cutlery and kettles, all of which are made of *metal*. Actually all the ninety-two elements existing in the world can be described as **metals** or **non-metals**, although sometimes a substance possesses attributes of both classes and it is difficult to know under which heading it should be placed. In general, certain characteristics are typical of a metal, although the exceptions are such that a non-metal may possess one or more of these characteristics and a metal may lack them. Most metals have a "metallic" lustre although a non-metal like graphite has the same kind of sheen. Metals generally are opaque, although gold can be made into sheets sufficiently thin to be transparent to light. The majority of metals are heavy and have a high specific gravity; aluminium and magnesium, however, are comparatively light and sodium and potassium have such a low specific gravity that they float on water. Most metals conduct heat and electricity well because of the presence of free electrons which

can move amongst the atoms of the metal. Generally metals are malleable (*i.e.* they can be hammered into thin sheets) and ductile (*i.e.* they can be drawn out into fine wire). If seen under a microscope a metal shows itself to be crystalline in structure, and sometimes, as in the case of the tungsten filament of electric lamps, a fine wire can be drawn out from a single crystal of the metal.

The ores of metals. A few metals such as gold, platinum and copper are to be found in their natural state and so are called **native** metals ; others, like iron and lead occur in compounds called **ores** and the pure metal has to be separated before it can be used.

EXPT. 76. **The metal lead obtained from a compound.** Make a small hollow in a piece of charcoal and place some litharge (an oxide of lead) in it. Heat strongly by means of a blow-pipe flame (Fig. 167), and notice the globules of the metal lead which separate.

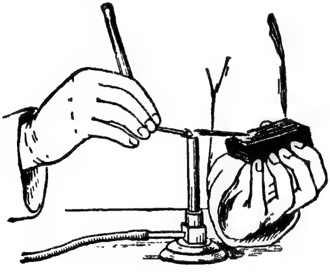


FIG. 167. REDUCTION ON CHARCOAL.

The litharge is an oxide of lead, and when heated strongly over the red hot charcoal the oxygen of the compound combines with the charcoal or carbon more readily than with the lead, so that the metal from the compound is left behind. This process of removing oxygen from a compound is called **reduction**, and it is the reverse process to the formation of oxides described in Expt. 63 when **oxidation** took place.

Various methods are used for extracting metals from their ores, but this principle of reduction is the basis of all of them. Sometimes such a high temperature is required for reduction that an electric furnace has to be used ; otherwise an ordinary furnace heated by coke or coal suffices. First of all, various rocky impurities are removed from the ore by mechanical or

FIG. 168. (i) EARLY EGYPTIAN COPPER VESSEL—ABYDOS.
(*From Evans' "Palace of Minos at Knossos".*)

other means, and then an ore which is an oxide is directly reduced by heating it with carbon. Ores in the form of other compounds, such as carbonates and sulphides, are first roasted in air to form oxides, and then reduced in the usual way with carbon.

Uses of metals and alloys. Two metallic elements may be mixed to form a new kind of metallic substance called an **alloy.** Thus bronze is composed of copper and tin, and brass of copper and zinc. These two alloys together with the metals gold, copper, iron, tin and zinc have been known from very early times and excavators of ancient cities have found gold ornaments, bronze and copper coins, brass and copper vessels (Fig. 168 (i)), weapons of war of bronze, copper or iron (Fig. 168 (ii)). Other metals such as magnesium and aluminium have only been

FIG. 168. (ii) SUMERIAN COPPER SCIMITARS FROM TELLO. About 3000 B.C.

in use for the last hundred years, and as mentioned on page 147 the increased use of aluminium for domestic utensils during the last twenty years is the result of the discovery of a cheap electrical method of separating the metal. A new alloy of magnesium and aluminium called magnalium is very strong and light and is therefore of great use in the construction of airship and motor parts. Another fairly new alloy is stainless steel ; the addition of chromium to the steel makes it rustless, so that it is of particular use for cutlery. A similar labour-saving use of metal is found in the chromium plating used on taps and bathroom fittings, chromium being a metal which does not corrode. Alloys often seen in the home are pewter, a mixture of tin and lead, which is used for tea and coffee pots, tankards and salvers, and German silver, an alloy of copper, nickel and zinc, from which forks and spoons are made.

Iron and steel. The most common and the most useful metal known to man is iron. It is by the use of iron and steel that the great engineering feats of this scientific age have been achieved.

Large quantities of iron are to be found in the earth, but not generally in the form of native iron. There are a number of different iron ores, compounds of oxygen with iron such as *magnetite* and *haematite*, compounds of the oxides with water, as in *limonite* and *gothite*, compounds of sulphur and iron in *iron pyrites*, and of carbon dioxide and iron as in *clay iron-stone* and *chalybite*.

These last two carbonate ores are generally found near coal, and the proximity of the coal and the iron makes such a region very suitable for iron smelting, as, for example, in the Midlands. The process of iron smelting is carried out by means of **blast-furnaces** (Fig. 169). Before the ore is placed in the blast-furnace it is first roasted (or calcined) by arranging it in stacks with fuel and heating it strongly. This drives off carbon dioxide and moisture and leaves the iron ore in the form of an oxide, known as **ferric oxide.** The oxide is then passed into the blast-furnace,

together with coke and limestone, through the cup and cone-shaped mouth at the top. The furnace itself is about 75 ft. high and 24 ft. wide, and is made of an outer shell of steel lined with heat-resisting bricks. Blasts of hot air, which has previously been heated in a furnace known as Cowper's stove, are forced into the heated mass by tubes near the base. The oxygen in this air combines with the carbon of the hot coke to form carbon monoxide, a reducing agent. This reduces the ferric oxide, and the iron separates out and works its way down until it can be removed in a liquid form by the tubes at the bottom. Above it, there is a lighter layer of melted slag formed from the limestone and silica from the ore, and this is removed at the slag hole. The liquid iron removed from the blast-furnace is run into moulds made in sand, and on cooling forms bars of **pig-iron.**

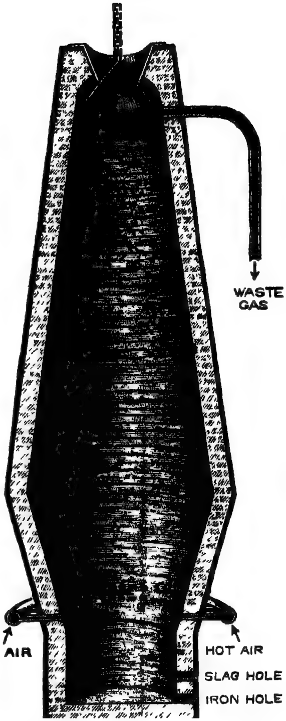


FIG. 169. A BLAST FURNACE.

Various kinds of iron and steel. When pig-iron is cast in suitable moulds it is known as **cast iron.** In this state, the metal is not malleable, and it is so brittle that it will not stand severe shocks. It is, therefore, only suitable for certain iron work, where it can be made in definite moulds, and need not be hammered afterwards. A more useful variety of iron that can be made from cast iron is **wrought iron**; this is much more tough and malleable and can be hammered into shape, rolled into plates or drawn into wires. Horse-shoes, nails and domestic articles are all made from wrought iron.

Wrought iron contains less carbon than cast iron, and by adding carbon to molten wrought iron or by removing carbon from cast iron, an iron containing an amount of carbon in between the two is obtained. This is **steel**, and its properties vary according to its treatment. If it is heated and then cooled quickly a hard but brittle metal is obtained ; if, on the other hand, it is heated cautiously and cooled more slowly, it is elastic rather than brittle ; it is then said to be *tempered* steel. By adding small quantities of other metals, such as chromium or manganese, to steel, many special alloy steels can be made, and there are now over a hundred different classes of steel suitable for a variety of purposes. Mention has already been made of the use of chromium in stainless steel. For making magnets, a silicon steel composed of iron and steel is particularly suitable for electro-magnets, while one containing cobalt is used for permanent magnets. For engineering purposes, very strong and hard alloy steels are made by adding tungsten or manganese to the iron. Tungsten steel is used for tools and parts of machinery, and manganese steel is placed to strengthen bends and crossings of railway lines.

One difficulty that is met with in the use of iron and steel is the tendency for it to rust ; methods of overcoming this problem have already been discussed in Chapter XII.

Carbon. In the industrial world and in domestic life one of the most common substances in daily use is coal. Coal is a compound consisting chiefly of the element **carbon**, and it is of vegetable origin. All kinds of plant and animal matter, whether living or dead, contain the element carbon, and the element itself exists in a variety of states. The finest and most valuable form of it is the **diamond**, a hard crystalline substance, capable of refracting light in such a way that scintillating colours are seen in it. Another common form with quite different properties is **graphite** ; this is really crystalline also, but it is opaque and black, and makes a mark on paper. Thus it is used for lead pencils (so-called), and also for making conducting surfaces for

electrical work and in electric furnaces. Ordinary soot from a burning flame or **lamp-black** is also a form of carbon, and it is of use for the manufacture of shoe polishes and ink. Wood, when heated so that the air cannot get to it, forms **wood-charcoal**, and coal when heated forms **coke** and **gas-carbon**; these three substances all consist of more or less pure carbon.

It was seen in Chapter XII that when charcoal or carbon was burnt in oxygen the gas carbon dioxide was formed, and a diamond, like other forms of carbon, will produce carbon dioxide if heated in air or oxygen.

Kinds of fuels. In early times, wood and charcoal were the fuels in common use for such domestic purposes as cooking food and warming houses. In the modern home, we can choose electricity or any of the fuels, coal, gas and oil as a means of lighting and heating. The various kinds of coal and oil are the most important fuels because, except in America, where natural gas exists, any kind of gaseous fuel is derived from one or other of them; moreover, electricity can only be generated when engines are worked by coal or oil or by water-power. *All fuels*—solid, liquid and gaseous—*contain the element carbon in a proportion varying according to the substance*; all, with the exception of charcoal and coke, contain hydrogen also.

Coal. Wood, peat, coal and anthracite are all of vegetable origin, the difference between them being due to the decomposition and pressure they have undergone. Most people have seen the impression of the fern-like leaves on pieces of coal, and these markings are evidence of the primeval forest in which the coal originally existed. These forests were submerged and covered with sediment as the result of earth movements, and after many thousands of years under great pressure the woody parts have become coal.

Peat represents the first stage in such a transformation and is produced by the decay of trees and swamp plants; the next stage is when, under pressure, a soft brown coal called **lignite** is

formed. As the result of more extreme changes coal is produced, different kinds varying in hardness and composition according to the conditions under which they are formed; the hardest and densest coal is **anthracite**, a fuel which is difficult to kindle, but which burns with no smoke, and produces more heat than other kinds of coal. A new kind of fuel—"**coalite**"—manufactured from coal by the Low Temperature Carbonisation Co., Ltd., is termed a cellular anthracite; it is smokeless and gives intense heat like anthracite, but it has not the same disadvantages of costliness and difficulty of kindling.

Composition of coal. The difference in composition of wood and the various kinds of coal is that less of the *volatile constituents* remain as the result of the changes during formation, so that anthracite contains the least amount of volatile constituents and consists approximately of 90 per cent. of *carbon*, while wood, as the other extreme, has only about 25 per cent. of carbon and a large proportion of volatile matter. Of the various coals, **cannel coal** is particularly rich in volatile constituents, and so is used for the manufacture of coal gas. In addition, all coals contain a little *moisture*, and a certain amount of mineral *ash*. The nature and proportion of the ash formed when a certain kind of coal is burnt is important from the domestic point of view, because of the clogging effect of ash in the grate and the deadening effect on the fire. Oxygen is essential for burning, and ash tends to cover the surface of the fuel and block the grate so that air containing oxygen has not free access to the burning matter.

Coal gas. When coal is raised to a high temperature out of contact with air, a large volume of inflammable gases is given off and, by separation and purification, coal gas is obtained.

EXPT. 77. **Substances produced when coal is burnt.** Place some powdered coal in a hard glass tube, and connect it to a U-tube immersed in a beaker of cold water. From the U-tube connect a tube to a trough of water, so that gas may be collected (Fig. 170).

Heat the coal, and collect several jars of gas. Smell the gas and apply a lighted taper to it. Remove the U-tube and pour off the watery upper layer. Smell this liquid and test its action on litmus. Smell the brown tarry liquid remaining in the U-tube. Examine the coke left in the hard glass tube.

This process of heating coal away from the air so that it breaks up into new compounds is called **destructive distillation.** It is different from the process of **combustion** that takes place in an ordinary fire grate when coal burns away to ash and the

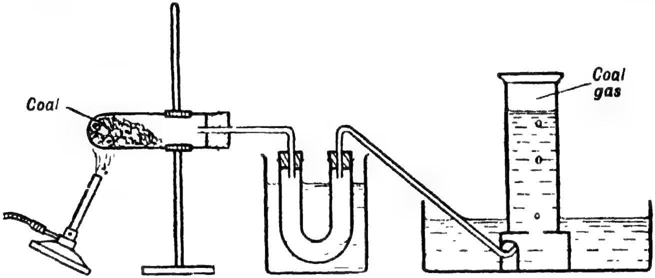


Fig. 170. When Powdered Coal is Heated, the Substances obtained are Coal tar, Ammoniacal Liquor, Coal Gas and Coke.

various constituents pass off in the form of vapours, smoke and soot. By the process of distillation, coke, which consists of nearly pure carbon, is left behind, and the volatile matter that passes off contains numerous important substances as well as coal gas.

The many substances formed during the manufacture of coal gas are termed by-products. The brown liquid **coal tar** is useful, not only for tar and pitch, but also for the manufacture of creosote, benzene, carbolic acid, various dyes and oils and numerous other substances. The watery liquid that smells of ammonia is **ammoniacal liquor,** and this is used chiefly for making a valuable fertiliser. ammonium sulphate. The gas collected burns with a smoky yellow flame ; it has a worse smell than ordinary coal gas, because certain sulphur compounds have not been removed from it. **Coke,** the residue

remaining, is lighter than coal and of a greyish tinge; it burns without flame and is useful as a cheap fuel.

At gasworks (Fig. 171), cannel coal is heated to red-heat in fireclay *retorts* and the products pass through the *hydraulic main* to the *condensers*. Here most of the coal tar and ammoniacal liquor condenses, and any that finally remains is removed by the stream of water flowing through the *scrubbers*. To make the gas suitable for household use, the sulphur compounds are removed in the *purifier* and the gas then passes

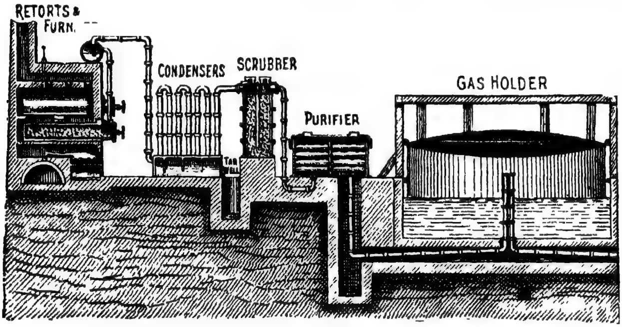
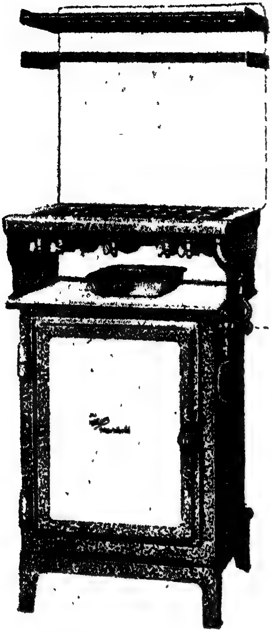


FIG. 171. THE MANUFACTURE OF COAL GAS.

to the *gasholder*, ready to be sent along the mains to the consumer.

Gas cookers. The use of gas for cooking has largely superseded the use of coal. In most houses in towns, cooking is done either by gas or electricity. Gas is generally the cheaper method, but electricity has the advantage of being cooler and cleaner. An up-to-date cooker of the "New World" type (Fig. 172) has a special thermostatic device for controlling the temperature of the oven, so that by setting the "Regulo" disc in the right position, food may be left to cook for a given time, without any danger of the temperature of the oven rising above a certain point so that the food gets spoiled.

Oils. The chief liquid fuel is **petroleum**, a mineral oil found in the United States, Mexico, South Russia, Burma and various



(i)

(ii)

FIG. 172. (i) A MODERN GAS COOKER. (ii) THE "REGULO" DEVICE FOR CONTROLLING THE TEMPERATURE OF THE OVEN.
(*By courtesy of Wilsons and Mathiesons, Ltd.*)

other places. It is generally obtained by boring holes and striking wells but sometimes it gushes out naturally (Fig. 173). Petroleum is a mixture of several hydrocarbons (that is, compounds of the elements, hydrogen and carbon); these have different boiling points and so may be separated by a process known as *fractional distillation*. As the boiling point of each liquid in turn is reached, the liquid distils over and is condensed so that eventually the various liquids are obtained separately. The one with the lowest boiling point and the first to distil over is **petrol**; next comes **benzine**, then **paraffin**, and finally various

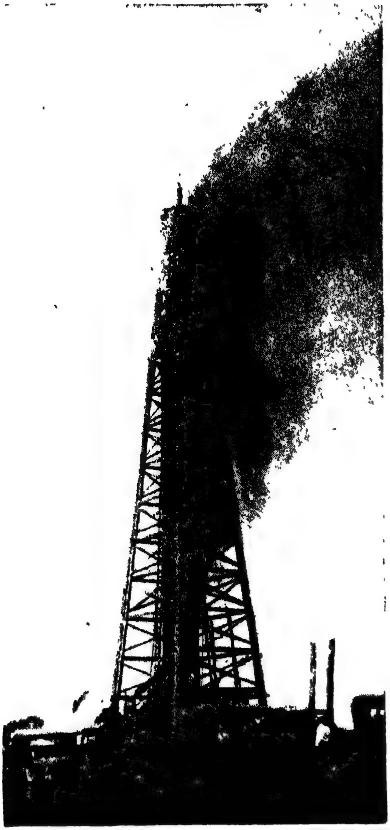


FIG. 173. A GUSHER SPOUTING OIL.

heavier lubricating and fuel oils. The two oils in most common use are petrol and paraffin.

Limestone. One of the most common chemical compounds occurring in the earth's crust is **calcium carbonate.** Large masses take the form of **limestone, chalk, Iceland spar** and **marble,** and ranges of hills such as the Pennines, the Cotswolds, the Chilterns and the North and South Downs are due to ridges of

limestone or chalk appearing above the surface of the earth. Calcium carbonate is also the chief constituent of such substances as egg shells, oyster shells and coral.

Chemical nature of limestone. The chemical formula for limestone is $CaCO_3$, and, as explained in the previous chapter, this means that a molecule of limestone consists of one atom of calcium, one of carbon and three atoms of oxygen. A change takes place when some of the substance is heated.

EXPT. 78. **Effect of heating chalk.** Place some powdered chalk in a porcelain crucible and heat it very strongly. The powder seems to alter little in appearance, but to find if a change has taken place compare the powder before and after heating, (1) by shaking a little of each on damp red litmus paper, (2) by adding a little water to each, (3) by adding dilute hydrochloric acid to each.

The change that has taken place is that heating has caused the gas, carbon dioxide, to be driven off from the compound. This may be represented by the equation :

$$\underset{\text{limestone}}{CaCO_3} = \underset{\text{lime}}{CaO} + \underset{\text{carbon dioxide}}{CO_2}.$$

The substance left after heating is lime or **calcium oxide** (CaO). This differs from calcium carbonate in that it turns red litmus blue, thus showing it forms an alkali, and it evolves heat and gives off steam when a few drops of water are added to it. The compound formed from the water combining with the freshly burnt lime (or **quicklime** as it is called) is known as **calcium hydroxide** (or **slaked lime**). This reaction may be represented by the equation :

$$\underset{\text{quick lime}}{CaO} + \underset{\text{water}}{H_2O} = \underset{\text{slaked lime}}{Ca(OH)_2}.$$

Slaked lime will dissolve slightly in water and form a solution known as **lime-water.** This is often given to babies to help them to digest their milk.

It was seen in Chapter XII that carbon dioxide is prepared by adding acid to chalk or marble. Thus effervescence occurs

when acid is added to the powdered chalk, because carbon dioxide is given off, but the acid has no such effect on the quicklime, because the carbon dioxide has already left it. This acid test is the means whereby geologists find out whether or not rocks are limestone ones. If they are, there is fizzing when a little acid is dropped on them.

Uses of limestone. The heating of limestone to convert it into quicklime is an important industrial process. It is carried out in **kilns**, in the modern form of which numerous openings make it possible for the fire to be kept going continuously, while lime is raked out at the bottom, and fresh supplies of limestone and fuel put in. The lime when slaked and mixed with sand makes **lime mortar**, a substance essential for building purposes. Another useful substance derived from limestone is **cement**; this is made by burning a mixture of limestone and clay in a special cement furnace (Fig. 174). A mixture of cement and gravel forms **concrete**, and this when cast over a steel frame and left to set, makes the strong structure known as **reinforced concrete.**

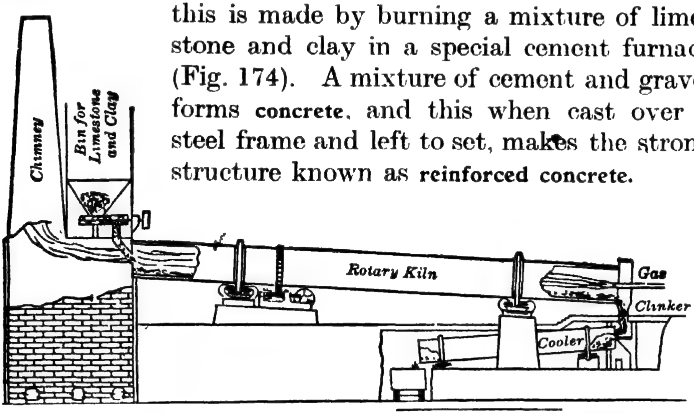


FIG. 174. A ROTARY CEMENT FURNACE.

Another important use of lime is, as mentioned on page 201, that of softening the water supplied by town mains; by Clark's process the addition of slaked lime causes the calcium bicarbonate to break up so that calcium carbonate is precipitated. Lime is also useful for agricultural purposes, as it neutralises acids formed in the soil by the decay of organic

FIG. 175. MAKING POTTERY.
(*By courtesy of Messrs. Doulton & Co, Ltd*)

matter, so that conditions are more favourable for plants to obtain their nutriment from the soil. Further uses of lime are in the manufacture of bleaching powder and whitewash, and in the purification of sugar.

Clays. Other very common substances occurring in the earth's crust are the various kinds of clays. These are soft plastic masses readily worn down by wind and rain, so that they never form ridges or hills. Where clay is at the surface the country is generally flat and gently undulating as, for example, in the valleys of Kent and Sussex or the Cheshire Plain. The **coal measures** are groups of rocks in which layers of clay alternate with ones of sandstone and seams of coal.

Clays are generally white or grey in colour, although some have a reddish tint, owing to the presence of impurities which are iron compounds. The chemical nature of clay is that it is a compound of water and the oxides of aluminium and silicon. Its purest form is **china clay** or **kaolin**, and this is used for making the best chinaware, although less pure forms are also

employed for cheaper china and pottery. The clay is suitably prepared and then, while in a plastic state, moulded by a potter using a potter's wheel (Fig. 175). To make it hard, it is heated (or fired) in a kiln several times. After the first firing it is still porous, so it is coated with a **glaze** and at the second firing this fuses and fills up the pores. Before glazing, coloured patterns can be painted on the clay by means of coloured metallic oxides. **Bricks** for building purposes are made in a similar way, their red colour being due to the iron impurities in the clay.

A mineral called **gypsum** is often found in clays ; a pure form of this is **alabaster**, used for ornaments and bowls.

Sand. Everyone is familiar with wide stretches of sand on the seashore, and this consists of broken fragments of minerals resulting from the wear and tear of other rocks. Most frequently the grains are particles of **quartz**, which have become rounded by rubbing against one another in water. The chemical nature of quartz is that it is an **oxide** of **silicon** known as **silica.** Silica is a compound present in the earth's crust in even greater quantities than calcium carbonate.

Sandstone is formed by sand becoming consolidated after it has become land by substances cementing the grains together into a hard mass of rock. In this form sandstone forms ranges of hills such as are seen in the lowlands of Scotland and in South Wales.

Silica. One form of silica is quartz, the chief constituent of sandstone. A clear and transparent kind of quartz, known as **rock crystal**, is used for making lenses for spectacles and optical instruments. Certain coloured crystals used as semi-precious stones are also forms of silica ; such are the **opal** of greenish and varied colours, the **chalcedony,** also of varied tints, the **amethyst,** purple in colour, the **agate** like a striped chalcedony and the **jasper** and **cornelian,** both of a reddish hue.

Glass. An important use of silica is the manufacture of glass from pure sand. The sand is heated with limestone and sodium carbonate ; the silicate of lime and soda

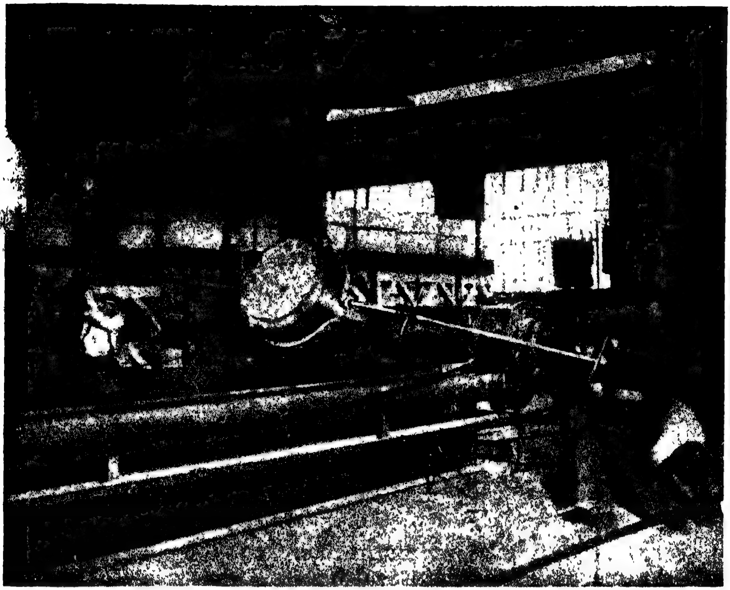


FIG. 176. POURING AND ROLLING PLATE GLASS.

so formed is commonly known as glass. The melting point is very high—about 1375° C.—but glass becomes plastic at a lower temperature than its melting point and can then be moulded, or blown to make bottles or rolled to form plate glass (Fig. 176).

CHAPTER XVI

ACIDS. ALKALIS AND SALTS. SOAP. CHLORINE. BLEACHING AGENTS. DISINFECTANTS. NITRATES. CROP ROTATION. NITROGEN CYCLE

Acids and alkalis. Some everyday substances are of particular value because they have the chemical property of being either acid or alkaline. It has already been seen in Chapter XII that the solution of a non-metallic oxide in water forms an acid. Other common substances may be classified as acids or alkalis ; if they produce no colour change in litmus they are said to be neutral.

EXPT. 79. **Common acid and alkali substances.** Obtain a little of each of the following substances : lemon juice, vinegar, common salt, borax, soda, tomato juice, tartaric acid, lime-water, ammonia, caustic soda, soap powder, sugar, sour milk. If the substance is solid dissolve it in some water in a test tube. To each, add a drop of litmus solution, shake the test tube and note any colour change. Enter your results in three columns according to whether the substances are acid, alkaline or neutral.

Liquids like vinegar, lemon juice and sour milk, have a sour taste and turn litmus red ; these two effects are characteristic of acids. Vinegar contains acetic acid ; lemon juice, citric acid ; sour milk, lactic acid.

Ammonia and washing soda are typical alkalis. In the home they are used for softening water and for a variety of cleaning purposes.

Sugar and salt form neutral solutions.

Mineral acids. Acids like citric acid and lactic acid, which occur naturally in ordinary food, are not much used for scien-

tific work. The three mineral acids in common use in the laboratory are sulphuric acid, hydrochloric acid and nitric acid. These three acids are powerful ones, and when undiluted, they have dangerous corrosive and burning effects.

Sulphuric acid is a colourless liquid of specific gravity 1·8. It chars animal and vegetable matter and causes burns if dropped on the skin. When diluting it for experimental work, acid must always be added gradually to water (*not* water to acid). When this is done, much heat is evolved and the solution gets very hot. Its formula is H_2SO_4, which indicates that a molecule of the compound contains two atoms of hydrogen, one of sulphur and four of oxygen.

Hydrochloric acid is a colourless gas until it passes into moist air, when it fumes strongly. It is very soluble in water, and the solution obtained when the gas is passed into water until no more dissolves, is concentrated hydrochloric acid, a liquid with specific gravity 1·2. Its formula is HCl, so that a molecule consists of one atom of hydrogen and one of chlorine.

Nitric acid is a fuming brown liquid of specific gravity 1·5. It is highly corrosive and if it touches the skin, it leaves a yellow stain. Its formula is HNO_3.

Properties of acids. The chief properties of acids are shown by their effect on metals and on carbonates (for example, chalk and washing soda).

EXPT. 80. **Properties of sulphuric acid.** (*a*) Pour 50 c.c. of distilled water into a beaker and read the temperature. Gently add about 10 c.c. of concentrated sulphuric acid to the water, stir the mixture and read the temperature again.

(*b*) Dip a glass rod into the dilute solution just made, and write a word on a piece of paper. When the liquid has dried, the writing is invisible. Now warm the paper near a flame, and notice how charring results and the word appears black.

(*c*) Add dilute sulphuric acid to zinc, iron and copper in test tubes. Hold a second test tube vertically with the mouth downwards, (Fig. 177 (i)), over the test tube containing the acid and metal. The

metal dissolves and the liquid effervesces because a gas is being given off. After a minute or two apply a lighted taper to the upper test tube; it pops, showing that hydrogen has flowed up into it and become mixed with the air. There is no effect with copper.

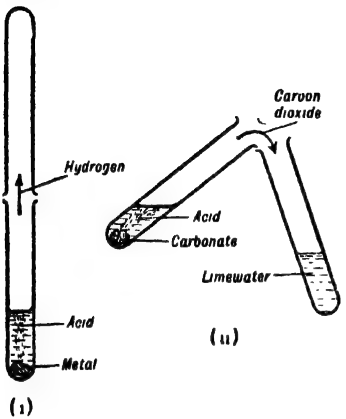


FIG. 177. TESTS OF THE GASES GIVEN OFF WHEN ACIDS ARE ADDED TO (i) METALS (ii) CARBONATES.

(*d*) Add dilute sulphuric acid to washing soda and chalk. Note the effervescence and pour the gas given off *downwards* into a test tube containing limewater (Fig. 177 (ii)). The carbonates dissolve and give off carbon dioxide.

EXPT. 81. **Properties of hydrochloric acid.** (*a*) Gently warm a little concentrated hydrochloric acid in a test tube. Notice the fumes that are given off as the gas comes out of solution.

(*b*) Carry out a similar experiment to part (*c*) of the previous one. Observe the different effect with copper.

(*c*) Add dilute acid to chalk and soda as in part (*d*) of previous experiment.

EXPT 82. **Properties of nitric acid.** (*a*) Put a piece of cork in some nitric acid in a test tube. Heat it and notice that the cork swells and is stained yellow.

(*b*) Add dilute acid to metals as in the previous experiment. No hydrogen can be detected but reddish fumes can be seen in the test tube. Notice that a blue solution is formed when the copper dissolves.

(*c*) Add acid to the carbonate and test as before.

With the exception of dilute sulphuric acid and copper, it seems that dilute acids dissolve metals, and hydrogen is evolved. *The element present in all acids is hydrogen*, and when chemical action takes place between an acid and a metal, the metal displaces the hydrogen from the acid. Thus:

$$\underset{\text{zinc}}{Zn} + \underset{\text{sulphuric acid}}{H_2SO_4} = \underset{\text{zinc sulphate}}{ZnSO_4} + \underset{\text{hydrogen}}{H_2}.$$

The zinc sulphate so formed is called a **salt**; the salts formed

from sulphuric acid are **sulphates.** In a similar way Expt. 81 gives us:

$$\underset{\text{iron}}{Fe} + \underset{\text{hydrochloric acid}}{2HCl} = \underset{\text{iron chloride}}{FeCl_2} + \underset{\text{hydrogen}}{H_2}.$$

This time the salt is iron chloride, the salts from hydrochloric acid being known as **chlorides.** In the case of nitric acid the effect is slightly different, because the hydrogen formed breaks up the acid still in the solution, and so a brown gas, a compound of nitrogen and oxygen, is evolved. The salts from nitric acid are **nitrates,** from acetic acid **acetates,** from oxalic acid **oxalates,** and from carbonic acid **carbonates.**

The properties of acids are then (1) they have a sour taste, (2) they turn blue litmus red, (3) they dissolve metals and hydrogen is evolved, (4) they dissolve carbonates, carbon dioxide being liberated.

Uses of acids. The three mineral acids are not met with in everyday life so frequently as those, like citric acid and lactic acid, which occur in food, Sulphuric acid is, however, found in the battery of motor cars, it being the essential acid for accumulators, and hydrochloric acid is used on a large scale in industry for bleaching coloured fabrics and for the manufacture of chemicals.

In the home, **vinegar,** which contains acetic acid, is used (1) as a condiment, (2) for preserving pickles, (3) as a liquid constituent of a paste for polishing metals, (4) to remove red ink stains, (5) to produce an acid effect when necessary in laundry work. **Lemon juice** (citric acid) can be used for cleaning marble, a form of calcium carbonate, and for removing stains. **Oxalic acid** is a poison and must be used with care. It is chiefly of value for removing iron mould, and ink stains, but the material must be well rinsed with hot water or any acid remaining may rot the material. **Tartaric acid** is used in cooking; it is a constituent of baking powder, and by its action on bicarbonate of soda causes carbon dioxide to be given off, this gas making the cooked materials "light".

Alkalis. It has been seen that when sodium and magnesium burn in oxygen, oxides are formed which more or less dissolve in water to form alkaline solutions. The oxide of another metal, iron, is insoluble in water. The oxide of a metal is a **base**, and when a base is soluble in water, it is called an alkali. So iron oxide, sodium oxide and magnesium oxide are all bases, but solutions of the two latter are alkalis also. Since in them the metallic oxide has combined with water they are termed **hydroxides**, for example, sodium hydroxide ($NaOH$).

Two important alkalis, sodium hydroxide and potassium hydroxide, have a strong corrosive and burning effect; they are **caustic alkalis**, and are generally called caustic soda and caustic potash. Calcium hydroxide or limewater is a mild alkali formed from a solution of slaked lime and water. Sodium carbonate or washing soda also gives a mildly alkaline solution. Ammonia hydroxide, commonly called ammonia, is not formed from a base but by the solution of ammonia gas in water.

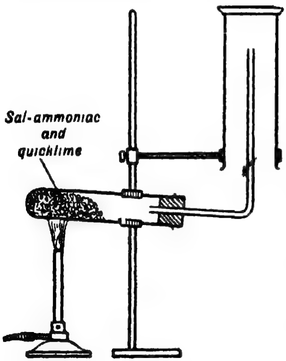


FIG. 178. PREPARATION OF AMMONIA.

EXPT. 83. **Preparation of ammonia.** Mix equal quantities of sal ammoniac and quicklime and place in a hard glass tube with a layer of quicklime on the surface of the mixture. Fit a cork and delivery tube as in Fig. 178. Warm the mixture gently and collect a jar of the gas by upward displacement, that is, the gas being lighter than air flows up and displaces the air in the gas jar. The characteristic smell of ammonia can readily be detected. Place the gas jar of gas mouth downwards in a vessel of water coloured with litmus; shake gently and notice how the water rushes up into the jar as the gas dissolves; the litmus changes colour as the alkaline solution forms.

Prepare another solution of ammonia by pointing the delivery tube downwards and connecting it to a funnel, the funnel being placed just below the surface of some distilled water in a beaker. The gas passes into the water and a strong solution can be made.

Uses of alkalis. Alkalis, such as washing soda, ammonia and lime water can be used for softening hard water. In this way, they assist cleaning operations, but their effectiveness in this direction is made more complete by their property of emulsifying grease. It has been seen that an emulsion is formed when an oil is broken up into small particles and held in suspension in a liquid. The presence of an alkali makes emulsification take place more readily so that things are more easily cleaned in water that is slightly alkaline. The detergents which are in such common use to-day for all kinds of washing processes act in a similar way by removing grease by mixing oil and water and causing oil-soluble and water-soluble combinations. Thus dirt and unwanted materials are wetted and detached from clothes, crockery and cutlery.

Soap. An important use of the caustic alkalis is in the manufacture of soap. When mutton fat (glyceryl stearate) is boiled with a solution of caustic soda, a soapy liquid is obtained. If salt is added, a salt solution is formed in which soap is insoluble; the soap then separates out.

EXPT. 84. **Preparation of soap.** Hang a muslin bag containing shredded suet in a beaker of water and boil the water hard, kneading the bag meanwhile, so that the tallow passes out. Skim off the fat, and place it in a large evaporating dish with three times as much caustic soda solution. Boil for half an hour and then add an equal quantity of salt solution. On re-boiling, the soap should separate out and rise to the top. Skim off this soap, and re-dissolve it in distilled water to wash it. Add salt solution and separate it out again. Skim off the soap and press it between blotting paper to dry it.

In Chapter XIII, it was seen that soap consists of sodium stearate, and in its manufacture the process that takes place is that :

$$\underset{\text{(mutton fat)}}{\begin{matrix}\text{glyceryl}\\ \text{stearate}\end{matrix}} + \underset{\text{(caustic soda)}}{\begin{matrix}\text{sodium}\\ \text{hydroxide}\end{matrix}} = \underset{\text{(soap)}}{\begin{matrix}\text{sodium}\\ \text{stearate}\end{matrix}} + \underset{\text{(glycerine)}}{\begin{matrix}\text{glyceryl}\\ \text{hydroxide.}\end{matrix}}$$

For other kinds of soap, olive oil or palm oil can be used instead of tallow, but the reaction between the oil and fat and the caustic alkali is similar. To manufacture soft soap, caustic potash is used instead of caustic soda.

The difficulty of making soap lather in hard water was discussed on page 198, and it was seen that the scum formed was calcium stearate. Thus :

$$\underset{\text{(soap)}}{\text{sodium stearate}} + \text{calcium bicarbonate} = \underset{\text{(scum)}}{\text{calcium stearate}} + \underset{\text{(dissolved)}}{\text{sodium bicarbonate.}}$$

Salts. A salt is formed when an acid dissolves a metal, and the latter displaces hydrogen from the acid. Another way in which a salt can be formed is by **neutralisation** of an acid by a suitable amount of an alkali or by a base. The salt so obtained is neutral and has neither an acid nor an alkaline effect on litmus.

EXPT. 85. **Preparation of common salt.** Measure 25 c.c. of caustic soda solution into an evaporating dish. Add dilute hydrochloric acid, drop by drop, stirring with a glass rod, and test the solution by letting a little solution fall from the glass rod on to red and blue litmus paper. When there is no effect on either kind of litmus, the solution is *neutral*. Evaporate it gently to dryness until only a white residue is left. Taste this white residue.

Common salt is sodium chloride, and it can be made by neutralising caustic soda solution with hydrochloric acid. Thus:

$$\underset{\text{caustic soda}}{NaOH} + \underset{\text{hydrochloric acid}}{HCl} = \underset{\text{sodium chloride}}{NaCl} + \underset{\text{water}}{H_2O}.$$

The neutral solution consists of a solution of salt in water and by evaporation the water is driven off, so that the salt remains.

The common salt in everyday use as a condiment and as a preservative of fish, meat and butter, is obtained by the purification of the mineral **rock salt.** This is found in the earth in layers of varying thickness. There are very large deposits in Wielieza in Galicia, and considerable quantities are to be found

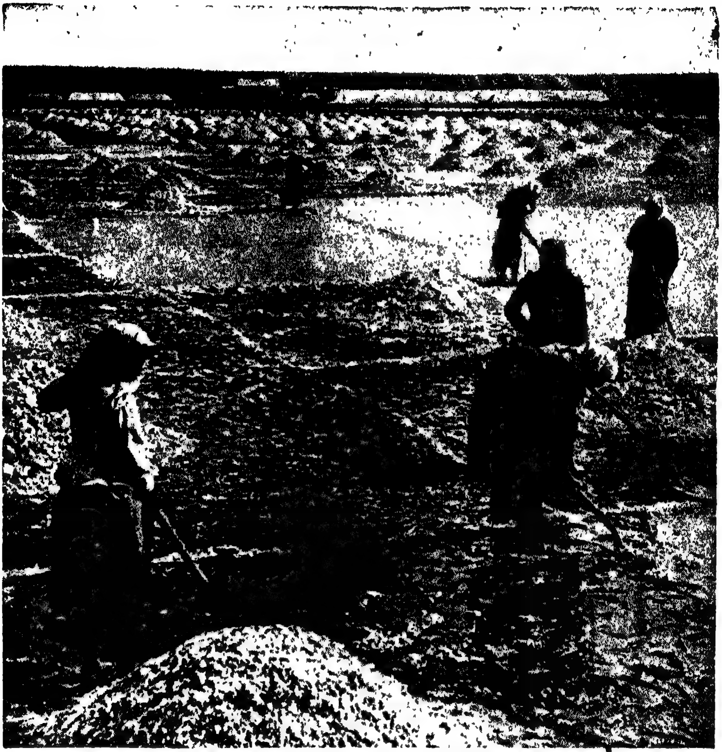


FIG. 179. HARVESTING SALT FROM THE CASPIAN SEA.

in Cheshire. Sometimes the salt is actually mined, but a simple way of obtaining it is by boring two holes down to the salt-bearing strata, sending water down one and pumping it as a brine solution up the other. When the brine solution is evaporated crystals of salt are left. Salt can also be obtained mixed with other substances in sea water (Fig. 179).

EXPT. 86. **Preparation of Epsom salts.** Measure 25 c.c. of dilute sulphuric acid into an evaporating dish. Warm gently and gradually add magnesium oxide, stirring well with a glass rod and

testing, as in the previous experiment, with litmus paper. When the acid has been neutralised by the base, filter the solution, evaporate it down and leave it to crystallise. Transparent crystals of magnesium sulphate (Epsom salts) are obtained.

Epsom salts are magnesium sulphate and the base, magnesium oxide, which is only slightly soluble in water, dissolves in sulphuric acid and neutralises it. Thus :

$$\underset{\text{magnesium oxide}}{MgO} + \underset{\text{sulphuric acid}}{H_2SO_4} = \underset{\text{magnesium sulphate}}{MgSO_4} + \underset{\text{water}}{H_2O}.$$

In the crystals of Epsom salts, some of the water is associated with the salt in crystal form, that is, it is water of crystallisation.

Chlorine. When hydrochloric acid is heated with manganese dioxide, a gas **chlorine** is evolved. This gas was the first one to be used as a poison gas in the Great War. It is of great value in industrial purposes, because it combines with slaked lime to form **bleaching powder,** a powder which removes the colour from fabrics and makes them white.

EXPT. 87. **Preparation and properties of chlorine.** (*a*) Place a mixture of manganese dioxide and concentrated hydrochloric acid in a flask and fit up the apparatus as shown in Fig. 180.

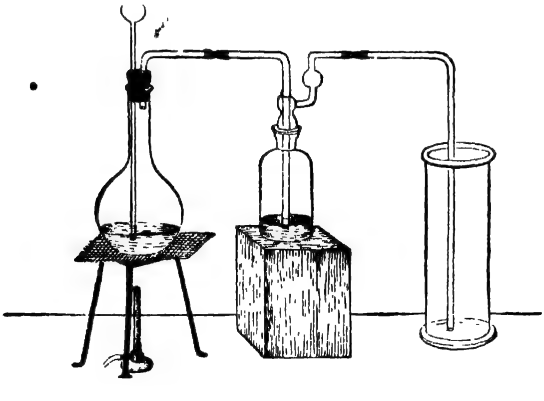


FIG. 180. PREPARATION OF CHLORINE.

The gas is passed through a wash bottle containing water to remove any acid which may be carried over, and it is then collected by downward displacement. The experiment should be carried out in a fume cupboard. Collect two jars of gas and cover them with greased plates. Note its greenish colour and irritating smell.

(*b*) Put a piece of bright red cloth in a jar of the gas and leave for a few minutes. Then add a little water and shake. When the chlorine is damp, the cloth is bleached and turns white. Repeat with a piece of paper marked with writing ink.

In the presence of moisture chlorine has a bleaching action, because it forms hypochlorous acid ($HOCl$) which is a bleaching agent.

Bleaching agents. Hypochlorous acid acts as a bleaching agent because it tends to form hydrochloric acid and liberate oxygen. Thus:

$$2HOCl = 2HCl + O_2.$$

The oxygen set free oxidises the colouring matter and the new substances formed may be colourless. For example, unbleached calico has a yellowish tinge because of the presence of brown colouring matter; a bleaching agent oxidises this brown substance so that it becomes colourless, and the calico then becomes white. Many bleaching agents are **hypochlorites**; that is, salts formed from *hypochlorous* acid; these should not be confused with the chlorides formed from *hydrochloric* acid. **Bleaching powder,** or **calcium hypochlorite,** which is made by passing chlorine over lime, is largely used in the manufacture of cotton fabrics; the materials are saturated with a solution of the bleaching powder, left for some time and then thoroughly washed. The washing process is necessary, because the bleaching powder solution may leave specks of the solid powder in the fabric, and these would cause rotting. To avoid this danger, laundries generally use a solution of **sodium hypochlorite**; white cotton and linen articles are treated with this to ensure that they are returned from the laundry a good colour.

Hypochlorites are not suitable for bleaching wool, silk materials or straw; their action is too corrosive and the

materials would be destroyed. For bleaching such substances, **sulphurous acid** is used, and this, instead of *oxidising* the colouring matter, as is the case with compounds of chlorine, *reduces* it to form colourless compounds. (The process of reduction is mentioned in Chapter XV.) Alternatively, delicate materials may be bleached with **hydrogen peroxide** (H_2O_2) ; the action in this case is an oxidation of the colouring matter, but there is no chlorine present to cause injury to the fabrics. Most people are aware of the bleaching effect of hydrogen peroxide in converting dark hair to a golden yellow, so that a brunette becomes changed to a " peroxide blonde ".

Disinfectants. It was mentioned in Chapter V that one of the impurities in the air of a room are the bacteria that cause such diseases as the common cold, influenza, diphtheria, and typhoid. The bacteria or " germs " may gain entrance to the body in a number of ways ; by the air breathed in, by contaminated food, by exposed cuts and abrasions or by direct contact with infected individuals. When **disinfectants** are used, they destroy these bacteria, while **antiseptics** retard or prevent their growth without actually killing them.

One simple method of disinfection is by exposure to sunlight ; in a few hours the ultra-violet rays will kill bacteria. Heat may have a similar effect, as, for example, when milk is pasteurised by keeping it at a temperature of between 145° F. and 150° F. for half an hour ; in this way bacteria causing tuberculosis, diphtheria, dysentry and typhoid are destroyed. Chemical disinfectants used in solution are very often **oxidising agents** ; they oxidise decaying animal and vegetable matter and render it harmless, as well as destroying microbes. To this type belong two substances already mentioned for their use in bleaching, sodium hypochlorite and hydrogen peroxide. A solution of the former is sold as a disinfectant, and the latter is a powerful antiseptic much used as a gargle and mouth wash. Two other liquids very similar in action are solutions of potassium permanganate and sodium permanganate. Both are pink in colour,

the latter being more generally known as Condy's fluid. Chlorine is also an active disinfectant.

Certain products of coal tar known as the cresols have powerful antiseptic properties, the most valuable of these being **phenol** or carbolic acid. Other useful antiseptics are iodine, which is an element, and the compound of iodine with carbon and hydrogen known as iodoform.

Nitrates. The salts obtained from nitric acid are known as **nitrates** and some of these compounds have valuable uses in the arts both of war and peace. Nitric acid and nitrates are essential for the making of such explosives as **trinitrotoluene** (T.N.T.), and **guncotton**, which are made by treating toluene and cotton respectively with nitric acid. **Dynamite** consists chiefly of nitro-glycerine or **glyceryl nitrate.** For more peaceful purposes, cotton treated with nitric acid by different processes produces such valuable substances as **celluloid** and **artificial silk.**

In **agriculture**, nitrates are of the utmost importance. It was seen in Chapter XII that plants require nitrogen for food. This and other less important elements they obtain in the form of soluble compounds dissolved in the water absorbed by the soil. (This will be discussed more fully in the next chapter.) The most important of such compounds are the nitrates and, in particular, **calcium nitrate** With the growth of plants, these nitrates get used up and, without some means of replenishing them, the ground would become sterile. Certain ways in which the replenishment takes place in Nature will be described in the next paragraph, but an artificial way of achieving it is by the use of natural or artificial manures. The most important artificial manure is **sodium nitrate**, which is imported in large quantities from the nitrate fields of Chile; it occurs there as a natural deposit on the ground (Fig. 181). Another artificial manure is ammonium sulphate, a by-product in the manufacture of coal gas; in this case the bacteria of the soil convert the compound into nitrates. Since it is possible that the

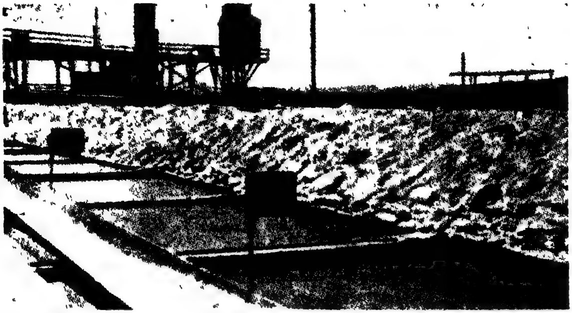


FIG. 181. CRYSTALS OF SODIUM NITRATE ARE HEAPED ON A LEDGE BESIDE THE VATS USED TO EVAPORATE THE SOLUTION.

supplies of Chilian nitrate will only last for a limited period, chemists have devised methods of making nitrates and other compounds from the nitrogen of the air, and these methods are now the chief sources of supply of agricultural fertilisers.

Crop rotation. Another method of refreshing the soil is by **crop rotation.** If crops with different food requirements are planted each year in the same ground, there is a much better yield of produce. A usual four-course rotation consists of root crops, barley or oats, clover, and wheat. Thus :

$$\begin{array}{ccc} \text{root crop} & \longrightarrow & \text{barley or oats,} \\ \uparrow & & \downarrow \\ \text{wheat.} & \longleftarrow & \text{clover.} \end{array}$$

Certain crops such as peas, beans, vetches and clover are of particular value because they enrich the soil by increasing its nitrogenous content. They achieve this because bacteria from the soil enter the root hairs and cause swellings on the roots ; in this way nitrogen from the air is " fixed " and converted into nitrogenous material. For this reason, the remains of a clover crop are dug into the soil to renourish it. Another advantage of crop rotation is that different crops are susceptible to different plant diseases and insect pests, so that with changes

each year there is less chance of any particular disease or pest becoming established.

Nitrogen cycle. One natural way in which nitrogen from the air becomes "fixed" in nitrogen compounds in the soil is by the lightning flashes in a thunderstorm. The discharge of electricity makes some of the oxygen, nitrogen and water vapour of the air combine to form nitric acid, and this is washed into the soil with the rain, where it reacts with limestone to form calcium nitrate.

Another way in which the soil gains nitrogenous compounds is from the death and decay of plants and animals, and from the waste products of animals. The nitrogen absorbed by the plant or animal is left in the substances of its body even when

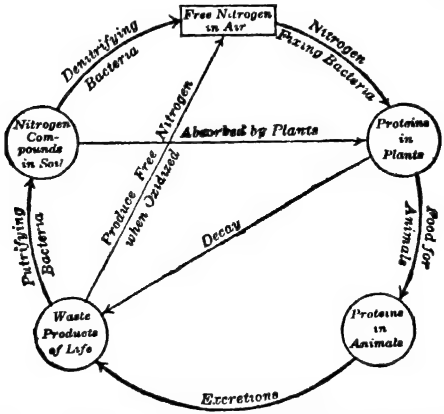


FIG. 182. DIAGRAM OF THE NITROGEN CYCLE IN NATURE.

it dies, but in this form it is useless to living plants as food. Certain bacteria in the soil, however, convert these remains into nitrates so that they replenish the soil. The waste matter from animals falls on the soil and is converted in this way, but most human sewage is sent into the sea or chemically destroyed by man. Some may slowly return to the atmosphere or remain in the form of ammonia and nitrates. In

addition to these *nitrifying* bacteria which convert decaying animal and vegetable matter into nitrates, certain other bacteria known as *denitrifying* ones, act upon the dead bodies of plants and animals and upon waste animal matter to turn the nitrogen in them into *gaseous* nitrogen which escapes into the air.

Fig. 182 shows how nitrogen circulates by these various processes, that is, it shows the **nitrogen cycle.** Nitrogen from the compounds in the soil goes to build up proteins in plants ; these provide food for animals and so build up proteins in animals. The excretions of animals and the decay of plants form the waste products of life, and these latter return to the soil as nitrogenous compounds, or produce free nitrogen in the air.

CHAPTER XVII

NON-LIVING AND LIVING MATTER. PLANT AND ANIMAL LIFE. NUTRITION. RESPIRATION. REPRODUCTION. ENVIRONMENT. HEREDITY AND EVOLUTION

Non-living and living matter. In making a study of man's environment, only the non-living things that surround him have so far been considered. As man becomes more civilized, he comes to depend more and more on the inanimate things he invents rather than on natural living things ; for example, he now uses motor-cars and aeroplanes as means of transport instead of horses and mules. Ultimately he may even make his food artificially by chemical means. But still living things will be of fundamental importance, because he himself is a living creature, and all the natural surroundings of the countryside consist of living matter or **organisms.**

There are differences between living and non-living matter. Five important characteristics possessed by most organisms and not by inanimate objects are :

1. Most living things can move—animals more freely than plants.
2. Living things require food. This food is changed, by chemical processes, into the substance of their bodies. This change, together with the absorption of the products of change, is called **nutrition.**
3. Most living things take in oxygen and give out carbon dioxide. This process is known as **respiration**

4. Most living things produce young ones, which grow into animals and plants of the same kind as their parents. This is **reproduction.**
5. Living things change with time in a rhythmic way. Most plants alter throughout the year with the seasons; the hearts of animals beat rhythmically so long as they remain alive.

Plant and animal life. The characteristics just mentioned are typical of almost all forms of life, but they are adapted differently to the two types of life—plant and animal. One obvious difference is that most animals can move freely from place to place, while most plants are in a fixed position. In the lower types of life, however, this distinction is not so sharply marked, and animals, like corals and sponges, may be fixed, while some extremely small green plants can swim about in the water in which they live.

The process of nutrition varies also. Most animals consume solid food and feed on plants and other animals. Plants require the raw materials of their food in a gaseous or liquid form, and obtain it from the air and soil around them. The main raw material is generally the carbon dioxide from the air, and nitrogen and other elements they obtain from the compounds dissolved in the water of the soil.

The respiration of plants also is less obvious than that of animals; they are not so energetic or active and so their respiration goes on at a slower rate.

Many animals breathe by lungs or gills, and plants by the intercellular spaces (that is, spaces between the cells) of their leaves and roots. Nevertheless, the process of respiration is essentially the same in both, and *oxygen* is essential for the life of most plants.

The power of growth and of reproduction possessed by plants and animals distinguishes them sharply from inanimate objects. Millions of bacteria may be produced from a single

bacterium in a day, and a plant may produce thousands of seeds. In the majority of cases, plants and animals produce their young by means of **eggs** and **sperms.**

Protoplasm. All living things are composed of tiny cells of a jelly-like substance called **protoplasm.** Chemists do not know what it is that gives *life* to this substance, but an analysis of dead protoplasm shows it to be made up chiefly of certain complicated chemical compounds called **proteins.** These compounds consist of the elements carbon, hydrogen, nitrogen and oxygen, together with a small proportion of sulphur and sometimes phosphorus as well. There is a great number of different kinds of protein molecules containing varying numbers of the atoms of these elements; one molecule of a protein may contain hundreds of atoms. Since these proteins, which are the essential constituents of living cells, exist in such variety, the actual protoplasm of different species of plants and animals varies considerably. All forms of protoplasm also contain a high percentage of water, some **carbohydrates,** some **fats** and some inorganic salts. Carbohydrates and fats contain the elements carbon, hydrogen and oxygen, but *never* nitrogen.

If an organism is to live and grow, it must be continually repairing old cells and making new ones. It must therefore always be building up protoplasm, and to do this, it must feed, absorb water and respire. Nutrition and respiration are essential for its life.

How plants obtain nutriment from the soil. Animals gain their nutrition by swallowing food material, but plants obtain the raw materials for their food in liquid and gaseous form from the soil and from the air.

The plant obtains some raw materials for its food from the soil because the elements it needs exist in the form of compounds in solution in the soil water, as, for example, nitrates, phosphates, chlorides and sulphates. Water containing these substances in solution enters the plant chiefly by means of the

FIG. 183 DIAGRAM SHOWING HOW A ROOT HAIR LIES AMONGST THE PARTICLES OF SOIL AND THE WATER CONTAINED IN THE SOIL

root hairs (Fig. 183) which spread out through the soil and come into contact with the water occupying the spaces between its particles. The water the plant thus receives serves to give it rigidity as well as supplying it with food.

EXPT. 88. **Observation of root hairs.** Scatter mustard seeds on several thicknesses of blotting paper placed on a saucer. Pour enough water into the saucer to make the paper thoroughly wet, place a piece of glass over the top, and leave in a warm place. After a few days, notice the appearance of the first root, this being covered with root hairs. Examine the hairs with a lens and notice how delicate they are.

When seedlings are being transplanted, the earth around the young roots should be disturbed as little as possible, so that the root hairs may not be damaged.

In Chapter XI the process of **osmosis** was described, and it is by this means that the solution containing dissolved substances passes into the plant. The root hairs consist of cells covered by a thin membrane of protoplasmic material. The sap inside the cell corresponds to the golden syrup of Expt. 54, and this

does not pass out because the protoplasmic membrane is semi-permeable; it lets the soil water pass into the sap, but does not let the sap escape. Furthermore, osmosis produces a pressure known as **root pressure** and this, together with other factors not yet understood, causes the sap to rise up through the minute capillary tubes that traverse the roots and stem of the plant, and pass along the veins of leaves and petals. If a snowdrop or some other white flower is placed with its roots in red-ink solution, after a short time the red solution can be seen to have reached the petals.

Transpiration. The solution containing mineral salts, etc., from the soil is very dilute, so that much unnecessary water is present. The plant therefore retains the food-salts and gives off the excess water to the atmosphere as water-vapour. This process of **transpiration** takes place chiefly through a number of small openings called **stomata** (Fig. 184), which can be seen with the aid of a microscope on the leaves of a plant and on young stems. In most cases there are many more stomata on the under surface of the leaf than on the upper. These stomata are each flanked by two kidney-shaped cells called guard-cells, and open into spaces between the cells of the leaf: the water-vapour escapes through the stomata into the atmosphere. Transpiration takes place more slowly if the surrounding air is already very humid, or very still, or if the plant is in the dark. Another function of the stomata is the taking in of air from the atmosphere outside. The plant needs the carbon dioxide of the air as *raw food material*, and

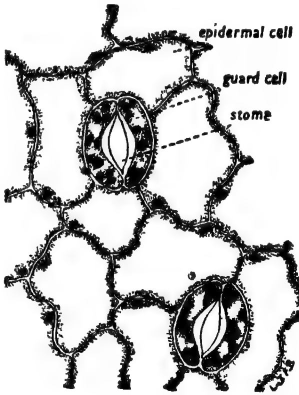


FIG. 184. PART OF THE UNDER-SURFACE OF A POTATO LEAF SHOWING THE STOMATA SURROUNDED BY THEIR GUARD CELLS.
(Magnified 100 times)

the oxygen for *respiration.* It absorbs the carbon dioxide only in the daylight, but the oxygen at all times, night and day.

How plants obtain food from the air. Of the various elements present as compounds in the protoplasm of plants, some are derived from the soil, some from the air. The most important element obtained from the soil is the nitrogen of the nitrates, together with small amounts of sulphur and phosphorus; in addition, the soil water can yield hydrogen and oxygen. But to get proper nourishment, the plant still needs a good supply of the element carbon, and instead of obtaining this from the carbonate rocks of the earth's crust, it utilizes the small amount of carbon dioxide present in the air; this process was at one time known as **carbon assimilation.** For this to take place, certain things must be present; carbon dioxide, water, light and **chlorophyll.** This last substance is one of the most marvellous ones existing in Nature, for by means of it the natural food supplies of the world are manufactured. It consists of a mixture of green and yellow colouring matters in the form of tiny bodies called **chloroplasts,** which lie in the protoplasm.

Now when carbon dioxide from the air passes into the leaves by means of the stomata, it encounters water drawn up from the roots, and, if sunlight is present, the chlorophyll uses the energy of the light to manufacture **sugar** and **starch** from the carbon dioxide and water. Some oxygen is left over, and this excess is returned to the air again through the stomata. In Expt. 64, on page 184 it was seen that a plant, in the presence of sunlight, feeds on carbon dioxide and gives off oxygen.

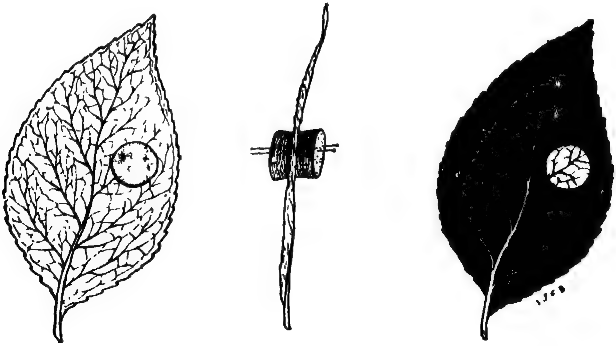
Since the process can only take place when light is present, it is now known as **photosynthesis** (from the Greek *phos*, light and *synthesis*, building up), a term more often used than the term 'carbon assimilation.' From what has been said about colour in Chapter VII, it is obvious that it is the *red* part of the spectrum that supplies the chlorophyll with the necessary

energy; the green colour of leaves must be due to their reflecting green light and absorbing the red. Plants, like mushrooms and toadstools, which are not green, do not feed by photosynthesis, but depend on decaying vegetable and animal remains for nourishment.

Starch and sugar are **carbohydrates**, that is, compounds of the elements carbon, hydrogen and oxygen. Such substances are essential to life and only plants can manufacture them in this way; this explains the importance of the chlorophyll on which the process depends. Another carbohydrate, **cellulose**, is also formed and this is the chief constituent of the walls of the cells of plants and of wood.

It is only while light is present that starch is formed in the leaves of the plant. This can be shown by a simple experiment.

EXPT. 89. **Formation of starch in leaves exposed to sunlight.** Take a plant with large leaves, and keep it in the dark for two days. Then cover a portion of one of the leaves by fixing corks opposite each other with pins (Fig. 185 (i)). Expose the plant to sunlight for a few hours. Break the leaf off the plant and remove the corks. Kill the leaf by holding it in boiling water for a few minutes



(i) (ii)

FIG. 185. (i) A CORK FIXED TO A LEAF BEFORE EXPOSING IT TO SUNLIGHT. (ii) NO STARCH IS FORMED IN THE PART OF THE LEAF CUT OFF FROM THE SUNLIGHT.

J.G.S.

and remove the colouring matter (the chlorophyll) by boiling it in methylated spirit. Place the bleached leaf on a white saucer and pour some iodine solution over it; it will turn blue everywhere except in the part that was not exposed to the sunlight (Fig. 185 (ii)).

A test for starch is that it gives a deep blue colour with iodine, and the experiment shows that exposure to sunlight caused starch to be formed everywhere in the leaf except the covered part. Starch is only made, however, while the leaf is in the air and sunlight, and a few hours after removing it from the light the starch would be found to have disappeared. If it did not disappear, the starch grains would block up the leaves, because starch is insoluble in water. At night, therefore, when photosynthesis ceases, the starch becomes converted into sugar, which is soluble in water and the sugar in solution travels to some other part of the plant, where it is often converted back to starch again. Thus starch is stored in the grains of wheat or in the tubers of potatoes. Sometimes, instead of being stored as starch, the sugar remains as free sugar; such is the case with sweet fruits, the sugar cane and sugar beet.

Respiration of plants. The process of photosynthesis just described is essentially a *feeding* process even although it is concerned with the taking in of carbon dioxide and the giving out of oxygen. The carbon dioxide is used as food and the oxygen is a waste product. In *respiration*, however, the plant takes in oxygen and gives out carbon dioxide. Both feeding and respiration are going on at the same time during the day, but the former process is so much more marked that the breathing is hardly noticeable. At night, during the absence of photosynthesis, respiration is more obvious, but it should be remembered that it is actually taking place at all times of the day and night.

EXPT. 90. **Carbon dioxide given off by seeds.** Place some germinating barley seeds in a muslin bag and hang them over some clean limewater in a corked bottle (Fig. 186). Leave the bottle

in a dark cupboard for two hours. (Darkness is necessary or the carbon dioxide produced may be re-absorbed by any green tissue, photosynthesis being the more marked effect.) On examining the bottle again, the limewater will be seen to have a film on it and on shaking up the bottle it will turn milky. If a thermometer is placed in the seeds they will be found to be at a slightly higher temperature than their surroundings.

FIG. 186. GERMINATING SEEDS HUNG IN A CLOSED BOTTLE OVER LIMEWATER CAN BE SHOWN TO GIVE OFF CARBON DIOXIDE.

The experiment shows that the seeds have given off carbon dioxide ; actually they have absorbed oxygen from the air in the bottle and given off carbon dioxide.

The amount of oxygen given off during the feeding process of plants is much greater than that absorbed during respiration, and this excess of oxygen helps to provide the balance of oxygen needed for the respiration of animals. At the same time, the carbon dioxide returned to the air by the animals in breathing provides food for green plants. Thus a cycle between plants and animals assists in keeping the proportion of oxygen and carbon dioxide in the air fairly constant.

Nutrition in animals. Animals take in water and solid food by the mouth and pass it to the digestive system, where it is converted into a form in which it can be assimilated by the body for the production of energy and new protoplasmic material.

It has been seen that plants only need water, nitrates, and other salts, and carbon dioxide. Animals, however, need more complex foodstuffs such as they can obtain from plants or other animals ; they cannot build up carbohydrates from the elements as plants can. The highest form of animal, man, requires in his diet, water and five kinds of foodstuffs ; (1) proteins, (2) carbohydrates, (3) fats and oils, (4) mineral salts,

(5) vitamins. The proteins he obtains from foods like meat, eggs and cheese; the carbohydrates from starch and sugar foods like bread, potatoes and sugar: the fats and oils from substances like butter and lard; the mineral salts from common salt, vegetables and fruit. Fig. 187 shows the proportion of water, fat, carbohydrates and proteins in different foods. Until the present century, these four classes of foodstuff were thought

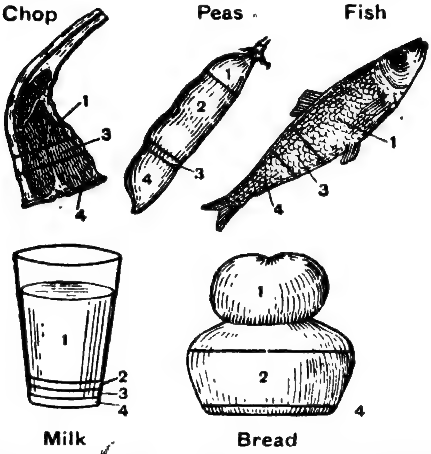


FIG. 187. THE PROPORTION OF WATER, CARBOHYDRATE, FAT AND PROTEIN IN SOME COMMON FOODS.

1 = water
2 = carbohydrate
3 = fats
4 = protein

to be the only essential ones, but during the last thirty years it has been shown that **vitamins** are of fundamental importance, if good health is to be maintained.

Vitamins. Minute quantities of vitamins are essential in human diet. The exact chemical composition of some of them has only been discovered quite recently, but for about thirty years it has been known that they are present in fruits like oranges, lemons and tomatoes, in fresh green salad and vegetables, in cereal grains and in milk and butter. Several vitamins have so far been discovered and they have been classified

by the names Vitamin A, Vitamin B, etc.; each has some particular value to health.

Vitamin A is of special importance to children, because they need it for their growth and for general health. It occurs in cod-liver oil, in egg-yolk, in milk and butter and in green vegetables.

There are a group of vitamins in the B group known as B_1, B_2 and so on, the latest one to be discovered being known as B_{12}. They are found in yeast, in eggs and in the germ of cereals, and serve as a preventive of nervous diseases and of indigestion and anaemia.

Vitamin C prevents scurvy, a disease from which sailors used to suffer when they lived on dried food. They are now given lime-juice or lemon juice, if fresh fruit and vegetables are unobtainable. Vitamin C is present in limes, lemons, oranges, grape fruit, tomatoes and cabbage.

Vitamin D stimulates growth. In its absence, the bones are insufficiently nourished, and rickets and other diseases may develop. It is present in cod liver oil and, to a less extent, in milk, butter and cheese. In sunlight, the body itself can manufacture vitamin D; thus real or artificial sunlight treatment is usually given to children suffering from rickets.

Several other vitamins are also known, but there are probably more yet to be discovered.

Respiration in animals. The reason why both plants and animals must take in oxygen is that they need energy. There is a continual reaction between the protoplasm and oxygen, which results in the protoplasm being oxidised and destroyed. This oxidation sets energy free, which is used by the plant and animal for movement, growth and other activities. The process of nutrition already described is essential for the building up of fresh protoplasm to take the place of that which has been oxidised. Respiration is equally important; the oxidation process must continue if life and activity are to be maintained.

Plants use stomata for gaseous interchange ; most animals use gills, lungs or other breathing apparatus. All the higher animals take in air by breathing it into their lungs ; the structure of these organs will be considered more fully in a later chapter. They contain numerous tiny blood vessels or capillaries by means of which the oxygen is absorbed into the blood, so that it can be carried about and distributed to the various regions of the body. The blood contains numerous protoplasmic bodies called corpuscles, and the red colouring matter in some of these, the **haemoglobin**, is the actual oxygen carrier. It unites with the oxygen in the lungs, and then carries it round the body, and gives it up to the protoplasm where necessary. When the protoplasm is oxidised, carbon dioxide is produced and this dissolves again in the blood stream in the form of sodium bicarbonate. In this form, it is carried back to the lungs again, where the carbon dioxide is set free and breathed out.

It was seen in Expt. 25 on page 76 that the expired air from the human body is much richer in carbon dioxide than that breathed in. The process just described shows that the carbon dioxide is a waste product formed when protoplasm is oxidised. In a similar way carbon dioxide is formed when wood is burnt, while heat energy is produced. Much of the energy obtained by respiration also is in the form of heat. Thus the germinating seeds in Expt. 90 were at a higher temperature than their surroundings ; while the living human body is always in such a state.

Excretion. The processes of nutrition and respiration lead to the formation of waste products, which have to be **excreted** or expelled from the system. Earlier in the chapter, it was seen how plants return excess water and unwanted oxygen to the atmosphere. The excretion of animals is in the form of solids, liquids and gases. Waste solid matter from food is excreted from the intestines, liquids are excreted by the skin and by the kidneys, and gaseous products by the lungs.

The waste products are the result of the oxidation that is

continually going on all over the body in the process of life. It was seen in the previous paragraph that waste carbon is removed with the expired breath. Waste nitrogen is changed into urea (a compound of nitrogen. carbon, hydrogen and oxygen) and this is expelled from the body dissolved in the water of the urine; waste hydrogen is converted into water, which may be removed as urine, or as perspiration from the skin, or as water-vapour in the air exhaled.

Reproduction. A further characteristic of living matter is its ability to reproduce its kind. Sometimes it achieves this by a simple process of division. For example, a bacterium, after growing to its maximum size, becomes narrowed about its middle and gradually separates up into two parts, the two new organisms thus formed being similar to the original one, so that the process can be repeated in them. This **fission** may take place in every bacterium two or three times an hour, so that as many as 200,000,000 may be produced from *one* individual in a day. Since the bacteria causing diseases produce poisons, this rapid multiplication might be very dangerous, but fortunately conditions are not always favourable for the nutrition and growth of all the organisms produced.

Another type of reproduction is the **budding** that takes place in yeast. Part of the cell wall swells out, and this part grows and becomes separated from the original cell. During the process, carbon dioxide is given off, and such **fermentation** taking place in a sugar solution containing yeast results in the formation of alcohol. Similar fermentation takes place when yeast is mixed with flour and sugar in making bread; the "rising" of the dough, and the porous nature of bread is due to bubbles of carbon dioxide being formed, and expanding when the bread is heated.

Both fission and budding are examples of **asexual reproduction,** that is, one individual organism *by itself* reproduces organisms of the same kind. More frequently, living matter in plants and animals requires a cell of one kind to mingle its substance with

that of another before reproduction can take place. The two kinds of cells are in most cases definitely male and female and are called **gametes.** When two gametes unite a new cell called a **zygote** is produced. This formation of new individuals as the result of the union of male and female gametes is known as **sexual reproduction** Often the gametes are of unequal size, the male gametes or **sperms** being smaller and more active than the female egg-cells or **ova.** After fusion of the gametes (or **fertilisation,** as it is called), the zygote develops into a miniature organism or **embryo,** and this, nourished by the food supplies around it, grows into a mature organism of its kind.

The production of seeds by plants will be studied more fully in the next chapters, and it will be seen that although it is sexual reproduction that takes place, sometimes the male gametes produced by the **pollen grains** exist in the *same* flower as the ova, in which case the flower is **hermaphrodite** ; sometimes certain flowers bear the pollen and others the ova, and then the individual flowers are male or female and are said to be **unisexual.** Most advanced animals are unisexual.* A common example of a hermaphrodite animal is the earthworm.

Environment. No living organism exists alone in the world, and its structure, habits and growth depend on the influences it receives from the world around it (that is, its **environment**). Such influences may be due to both animate and inanimate objects ; for example, the living organisms in a pond depend on each other and on the water around them. The latter, although inanimate, varies considerably in temperature in winter and summer, and living things must adapt themselves to such changes if they are to survive. Moreover, they must be able to secure the oxygen necessary for their respiration, either from the air dissolved in the water or by rising to the surface, and their nutrition from other plants or animals near them.

It seems, then, that all living things must adapt themselves to their environment in order that they may obtain what is

essential for their life. Accordingly they adjust themselves to the conditions of *air*, *water*, *food*, *light*, *temperature*, *gravity* and the other *living things* that surround them. It can easily be observed that seedlings grow towards the light (Fig. 188) and leaves tend to twist round so that the light falls on them at right angles; such movements of the plant in response to light are called **tropisms.** When a seed begins to develop, it is the effect of gravity which makes the shoot grow upwards and the root downwards. Animals also are extremely sensitive to the influence of gravity, and it is only by delicate adjustment of their muscles that they are able to balance themselves; everyone knows how easy it is for a human being to feel giddy, when looking down from a height. The animals, with their complicated nervous system, are more sensitive to their environment than the lower organisms, for they respond to stimuli of touch, sound, taste and smell as well as those of heat and light.

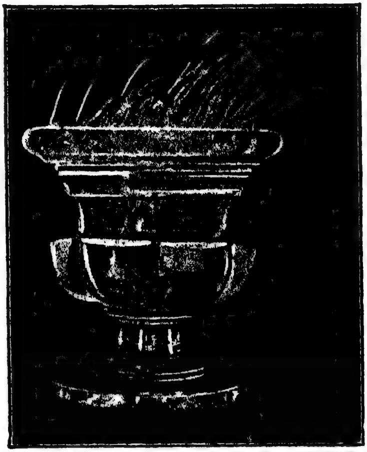


FIG. 188. MUSTARD SEEDLINGS GROWN OVER WATER AND ILLUMINATED CHIEFLY ON ONE SIDE, BEND OVER TOWARDS THE LIGHT.

Heredity and evolution. In many of the rocks of the earth's crust, there can be found fossilised remains of plants and animals that existed many thousands of years ago. A study of these has led to the belief that living organisms existing now are all descended from earlier forms, although, in the course of time, these forms have gradually varied from their original nature. For example, Fig. 189 shows how the horse in many generations has developed a foot particularly adapted to speed in running; the original five-toed horse was a little animal about

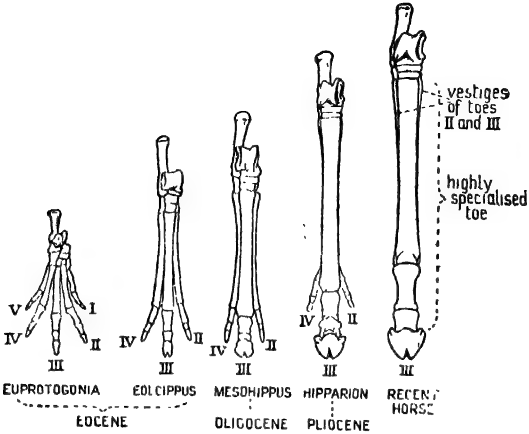


FIG. 189. THE EVOLUTION OF THE HORSE'S FOOT.

one foot high, and during thousands of years the modern type of horse has gradually developed. It is generally thought that all the complicated types of living matter existing to-day have, in the course of millions of years, developed from the simplest of organisms ; this extraordinary progress of life is known as **evolution.** In man himself is found the most advanced product of evolution, a highly developed living organism with qualities of mind and spirit which lift him above the other animals.

It is by the **variations** in successive generations of living matter that evolution has taken place, but although scientists have made detailed study of some of the variations that have occurred, very little is known of the *cause* of variation. **Charles Darwin** (1809-1882) made a great study of evolution in plants and animals, and his book *The Origin of Species*, published in 1859, gave a tremendous impetus to scientific thought. Darwin suggested that certain types of plants and animals tended to prosper and survive because, in the struggle for life, they could make the best use of their environment. Thus there was a

"survival of the fittest", the "fittest" being those which could make the most of their environment, and most readily adapt themselves to any changes in it.

Although the fact of variation or evolution is generally accepted nowadays, there has been much criticism of Darwin's explanation. The characteristics of any living organism depends not only on its environment, but also on heredity, that is, on its resemblance to its parents. No offspring are precisely like their parents, and variations occur in each successive generation. The Moravian monk **Gregor Mendel** (1822-1884) investigated the way in which characteristics and tendencies are inherited, and the principles of inheritance which he has discovered are of great value to science.

Opinions may differ as to the cause of the variations in living matter, but it is certain that evolution takes place and that such variations do occur. It seems that *heredity* plays an important part in determining the nature of the offspring produced and *environment* influences their chances of survival.

CHAPTER XVIII

FLOWERING PLANTS

General structure of flowering plants. Much of the beauty of the countryside is due to the many varieties of flowering plants occurring there. Plants of this type are all similar in structure, although they may show considerable differences of size, shape, and colour. Thus they all have four parts, (1) the *root*, (2) the *stem*, (3) the *leaves*, and (4) the *flowers* (Fig. 190). Each of these parts or **organs** of the plant has its definite work to do. The root must absorb water and dissolved substances from the soil ; the stem must conduct water and supplies of food to the rest of the plant ; the leaves must serve for nutrition and respiration ; and the flowers must cause reproduction by producing seeds from which new plants can be grown.

The structure of a seed. It was seen in the previous chapter that for reproduction to take place in a flowering plant, the ovum must be fertilised by sperm produced by the pollen. The *fertilised* ovum (zygote) with its surrounding food supply is a seed, and this, if given suitable conditions of air, water and warmth, can **germinate,** that is, begin to develop into a plant.

EXPT. 91. **Examination of (a) a bean, (b) a wheat grain.** Notice that these are hard, dry and wrinkled. Put them to soak in water for a day, and then examine them again. Observe that they have swollen and become softer, while the wrinkles have disappeared.

(*a*) Notice the black mark on the bean, which is the scar of where it was broken from the pod. Squeeze the seed, and a drop of water will ooze out of a tiny hole called the **micropyle** at one end of the scar. With a penknife, carefully remove the outer coating of the seed ; this is called the seed-coat or **testa.** Inside will be found two white

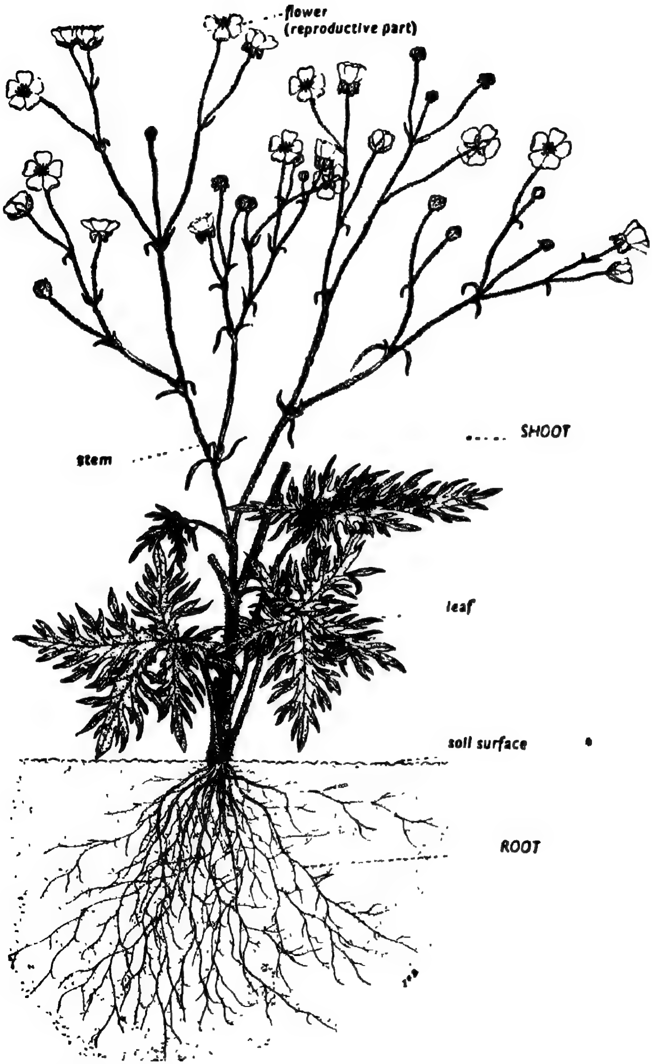
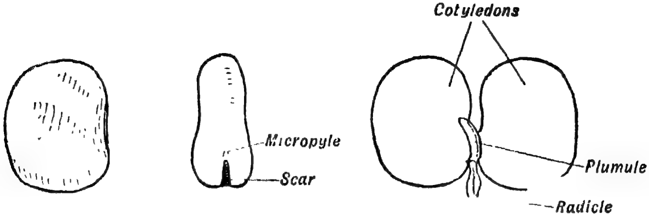


FIG. 190. THE DIFFERENT PARTS OF A BUTTERCUP PLANT.



Side view. End view. Testa removed and Cotyledons opened out.

FIG. 191. THE SEED OF THE BROAD BEAN.

kidney-shaped portions. Notice these are joined together in one place, and open them out gently like the leaves of a book (Fig. 191). The embryonic plant can now be seen. Notice the little root (or **radicle**), which points towards the micropyle and the young shoot (or **plumule**). The two large white pieces are seed-leaves (or **cotyledons**), and in the bean, these serve as a food supply for the embryo.

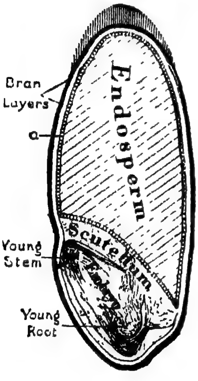


FIG. 192. GRAIN OF WHEAT CUT ALONG ITS LENGTH TO SHOW THE STORE OF FOOD (ENDOSPERM) OUTSIDE THE YOUNG PLANT. (Magnified)

(*b*) Remove the testa of the wheat grain and notice a small bulge at one end; this is the embryo. Carefully loosen it from the rest of the grain, and notice it is only a small part of the whole. The larger part of the grain consists of a white starchy part called the **endosperm** (Fig. 192); this serves as a food supply for the embryo.

Test both the wheat endosperm and the bean cotyledons with a solution of iodine to show that they are chiefly made of starch.

The embryonic plant always has a young shoot, the plumule and a young root, the radicle. Usually, as in wheat, maize and castor oil seeds, there is a part of the seed, the endosperm, which provides food for the embryo. In the case of the bean, however, there is no endosperm and food is stored in two modified leaves, called cotyledons. The apple and the pea are other seeds which have no endosperm. A hard coat, the testa, surrounds the seed and protects it.

Germination of a seed. For a seed to begin to grow it needs (1) warmth, (2) water, (3) air. Thus it often lies dormant during the cold winter months, and only begins to sprout when the first warm days of spring arrive. The stages in the early life of the seed, from the time it begins to grow until the first foliage leaf appears, can be called its **germination.**

When the temperature of the soil is sufficiently above freezing point, the seed may be ready to develop. Water from the soil is absorbed by the seed, and when a good supply of *water* has been absorbed, the food reserves in the endosperm or cotyledons become available for the embryo, and cells form in the radicle and plumule. Then the radicle forces its way out through the micropyle, and grows downward to form a root. As this gets bigger, the break in the testa becomes sufficient for the plumule to find its way out and grow upwards. Such an active process requires energy and this is supplied by the respiration of the foods stored in the seed; Expt. 90 showed that germinating seeds respire. The oxygen required for respiration is obtained from the *air* of the soil; it is usually advisable, therefore, to sow seeds in light soil, where there is plenty of air between the particles.

Expt. 92. **The growth of seedlings from bean, castor oil, wheat and mustard seeds.** Obtain four wooden boxes and put damp sawdust in them to a depth of a few inches. Plant the beans $\frac{1}{2}$-inch below the surface and about an inch apart. Scatter the smaller seeds thinly and give them a light covering of sawdust. Leave the boxes in a warm place, keeping them covered with glass until the seedlings appear so that the surface does not dry up. Make drawings of the seeds at intervals after the radicle has first appeared and so record the various stages of germination. Notice particularly any differences in the various kinds of seedlings, as, for example, the difference in behaviour of the cotyledons of the bean and the castor oil seeds.

Small seeds germinate more quickly than large, and mustard seeds generally do so a day after they are sown. Fig. 193 shows some stages in the germination of a bean. In this case, the cotyledons remain below the surface of the ground in order to supply the

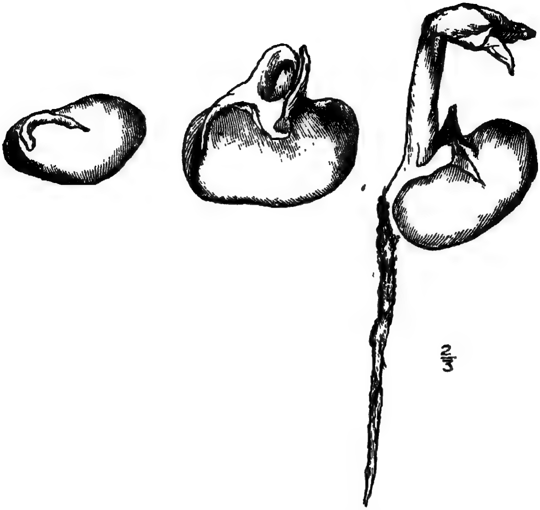


FIG. 193. GERMINATION OF BROAD BEAN.

embryo with food. The castor oil embryo, on the other hand, has an endosperm from which it can obtain food supplies, so that its cotyledons are not required for this purpose; they are, therefore, pulled above the soil with the young shoots, and become green as they develop chlorophyll in the light. In this way they grow to form the *first* foliage leaves, and are different from the normal ones. The first foliage leaves of the bean, however, are formed above the soil, and do not differ from later ones.

Once the root has become established in the soil, and the shoot has developed some foliage leaves, the plant can obtain water and nutrition by means of its root-hairs and leaves as described in the previous chapter. The seedling then no longer needs to obtain its food supplies from the seed itself, and the latter rots away.

The roots. From the radicle of the seedling the **roots** of the plant develop. Their two chief uses are (1) to anchor the plant firmly in the soil, so that it is not easily disturbed by the wind or animals, and (2) to provide the plant with water and dissolved substances from the soil. If the root consists of a

main portion, which has developed from the radicle with branches growing off it, it is called a **tap root**; the wallflower has a root of this kind. Sometimes such a root swells and food is stored in it; thus vegetables like the beet, the carrot, and the parsnip are all swollen tap roots in which sugar or starch substances have accumulated (Fig. 199).

A different type of root is to be formed in plants in which the radicle has ceased to grow and has withered, its place being taken by numerous fine roots growing from the base of the stem; this is a **fibrous root.** Fig. 194 shows the fibrous root of a wheat plant.

In addition to main roots like the tap root or the fibrous root, a plant may grow extra roots which do not spring from the radicle, but from the stem or leaves; these are called **adventitious roots.** Thus the ivy plant develops these roots on its stem to assist it in climbing (Fig. 195), the strawberry plant develops adventitious roots and tufts of leaves on the runners which lie along the ground, and these sometimes form new plants. When new flowering plants are formed by some other means than by seeds, **vegetative reproduction** is said to take place. Another example of this kind of reproduction

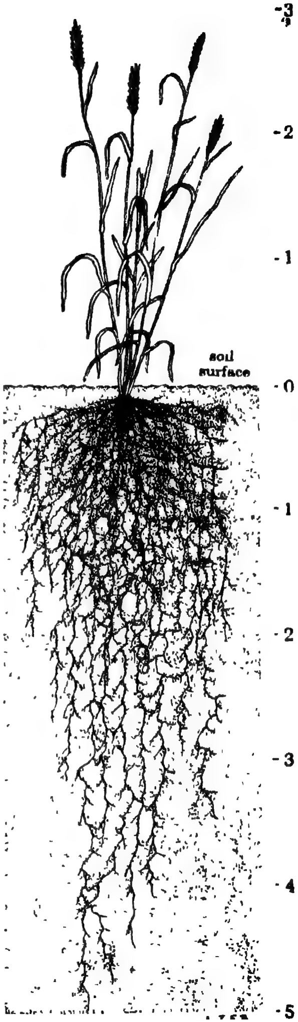


Fig. 194. The Fibrous Root of a Wheat Plant.

J.G.S.

FIG. 195. IVY CLIMBING A WALL BY MEANS OF ADVENTITIOUS ROOTS.
(*Photo : Henry Irving.*)

is the method by which gardeners grow roses, geraniums and other garden flowers from " cuttings " ; adventitious roots develop from the ends of the stems placed in the soil. Sometimes plants store foodstuffs in their adventitious roots ; thus the dahlia (Fig. 196) and the celandine have fleshy roots called **root-tubers** in which food is stored for the winter. Root-tubers are of great use for spreading plants by vegetative reproduction, as new plants can be formed from each tuber.

In Expt. 88 the root hairs of mustard seeds were observed, and the way in which they absorb water and dissolved substances from the soil has been described in the previous chapter. The root hairs grow a short distance above the tip of the root, and at the tip itself is a darker part called the **root-cap** ; it is

this part of the root which is continually growing, and the pointed end helps it to force its way forward through the soil. As the root gets longer, the older root hairs die, and new ones form close to the tip.

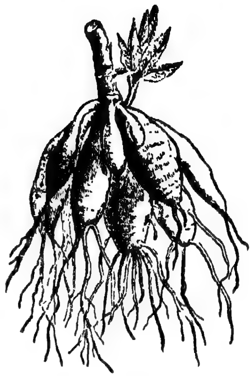


FIG. 196. ROOT TUBERS OF DAHLIA. (*After Figuier*)

The stem. When the seed germinates, the radicle grows downwards and develops into a *root*, while the plumule grows upwards and develops into a shoot. The essential difference between a root and a stem is that the latter bears **buds.** Thus the young shoot consists of a main stem with a **terminal bud**; if this is a leaf bud, it opens out and the growth of the main stem continues; if it contains a flower, growth in the direction of the main stem ceases once the flower has opened. Leaves grow from the stem at points called **nodes,** and generally more buds are borne in the angle (called the *axil*) between the leaf and the stem; these are called **axillary buds** and if they are leaf ones, they grow out to form branch stems. In this way all the foliage of the plant gradually develops, and it is the chief function of the stem to bear this foliage.

FIG. 197. SECTION OF LARCH STEM SHOWING YEARLY RINGS OF WOOD.

Some stems contain chlorophyll and are green; they then possess a certain number of stomata like leaves do. Older stems which last two or more years are woody, and are covered with a layer of cork called **bark.** Each year new wood

is added and the difference in its texture makes it possible to see the successive yearly layers ; thus the age of a tree can be calculated by counting the rings across its cut trunk (Fig. 197).

In some cases, a stem may have other uses than that of supporting leaves and flowers. It may be used for climbing as, for example, in the convolvulus, the scarlet runner, and the honeysuckle; such plants twist their less robust stems round the stouter ones of other plants to raise themselves. Plants like the white bryony (Fig. 198) and the virginia creeper develop tendrils from their stems to assist them to climb, while the ivy achieves this effect by its adventitious roots.

FIG. 198. THE STEM TENDRILS OF WHITE BRYONY.

Sometimes stems grow underground and are called **rhizomes** ; they are distinguishable from roots because they bear buds. Often an underground stem becomes swollen, because the plant uses it for storing food, generally in the form of starch. A common example of this is the potato plant (Fig. 200) ; it possesses underground branch stems which swell at the ends to form **tubers** or potatoes ; the "eyes" of the potatoes are really leaf-buds in the axils of scale leaves, and from them shoots can sprout and produce adventitious roots at their bases to form new plants. **Corms** and **bulbs** also consist of underground shoots in which food is stored. If a crocus corm is cut through (Fig. 199), it can be seen to consist of a short rounded stem with

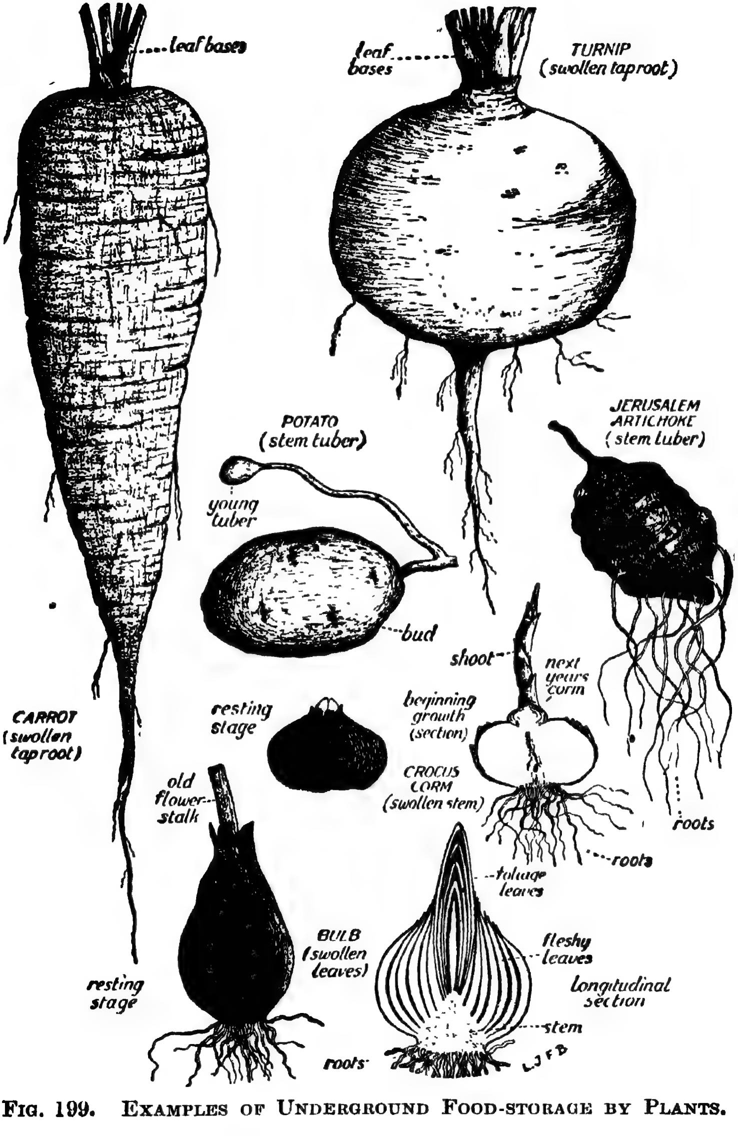


FIG. 199. EXAMPLES OF UNDERGROUND FOOD-STORAGE BY PLANTS.

one or two buds at the top, which will sprout in the spring to form new leaves and flowers, the food for their growth being provided by the starch of the corm. In a bulb (Fig. 199) there is a short flattened stem at the bottom, and from this there spring fleshy leaves which contain a store of food and bear flower buds. The difference between a corm and a bulb is that the former stores food in a swollen stem, while the latter uses its leaves for the purpose.

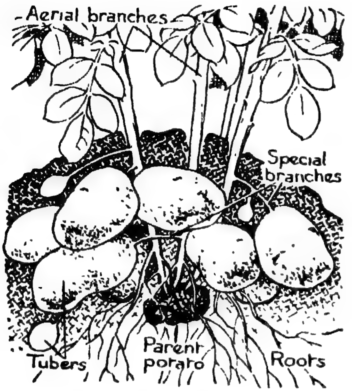


FIG. 200. A POTATO PLANT, SHOWING HOW THE YOUNG POTATOES, OR STEM TUBERS, ARISE.

The leaves. Leaves are attached to the stem at nodes; the part of the stem between them is called an **internode** and there are no appendages to the stem at such places. Generally a **leaf-stalk** connects the leaf to the stem, although in certain bulb plants, like the daffodil and the tulip, there are no leaf-stalks present. The broad flat part of the leaf is the **blade,** and throughout the blade there is a delicate network of **veins** which serve as channels for conducting water to, and food from, the leaf. Leaf skeletons of decayed leaves can often be found in woods, and these show the delicate tracery of the veining of a leaf very clearly. Generally, the veins branch out from a central main one, but in long narrow leaves like those of the iris and daffodil the veins are parallel. Fig. 201 shows a variety of different kinds of leaves. A leaf consisting of one leaf blade like the elm is a **simple leaf,** while one made up of several leaflets like the horse-chestnut is a **compound** one. Most British trees shed their leaves in the autumn and develop new ones in the spring; these are **deciduous** trees. Others which retain their foliage during the winter months are said to be **evergreen.**

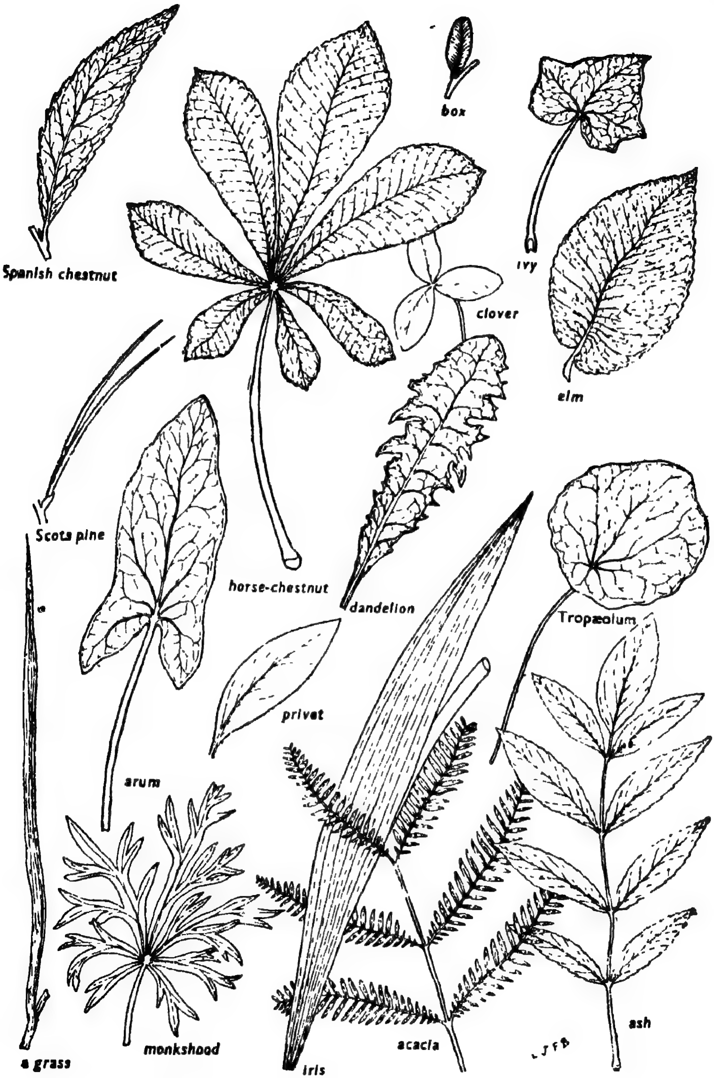


FIG. 201. TYPES OF FOLIAGE LEAVES.

It has already been seen that leaves are of vital importance to the plant for transpiration, nutrition and respiration, and they often are adapted to assist these processes. A tree like the Scots pine, for example, which grows in places exposed to the sun and wind, has needle-shaped leaves, so that transpiration is not excessive (Fig. 201), and most leaves are in such a position on the plant that they receive as much light as possible.

The flower. The flower is the reproductive organ of the plant, for it is in the flower that the seeds develop from which new plants can be grown. It is true that new plants can readily be obtained from tubers, bulbs, runners and cuttings, but this method of vegetative reproduction results in a deterioration of the stock after a few generations. For example, potato growers find it necessary to start new stocks of certain kinds of potatoes from seed occasionally instead of from tubers; otherwise a particular type of potato does not maintain its standard.

To understand the structure of a flower, it is essential to take a number of different flowers and examine them carefully. If the flower is cut down longitudinally through the centre with a sharp knife, the various parts of it can be seen more clearly. Most complete flowers consist of four **whorls** or groups of organs; these are borne on a swollen structure at the end of the stem called the **receptacle.**

The buttercup. A common flower to be found everywhere in the countryside is the **buttercup.** The plant has a bitter juice, so that the flowers often remain untouched by animals, when daisies and clover have been nibbled away.

On examining the buttercup (Fig. 202), the outermost whorl, the **calyx,** is seen to consist of five small green leaves called **sepals**; these enclose the base of the flower and protect the more delicate inner organs. Within the calyx is the **corolla**; this is made up of about five yellow **petals.** If a petal is removed and examined carefully, a little pocket called a **nectary** can be seen at its base; this contains nectar, a sweet honey liquid

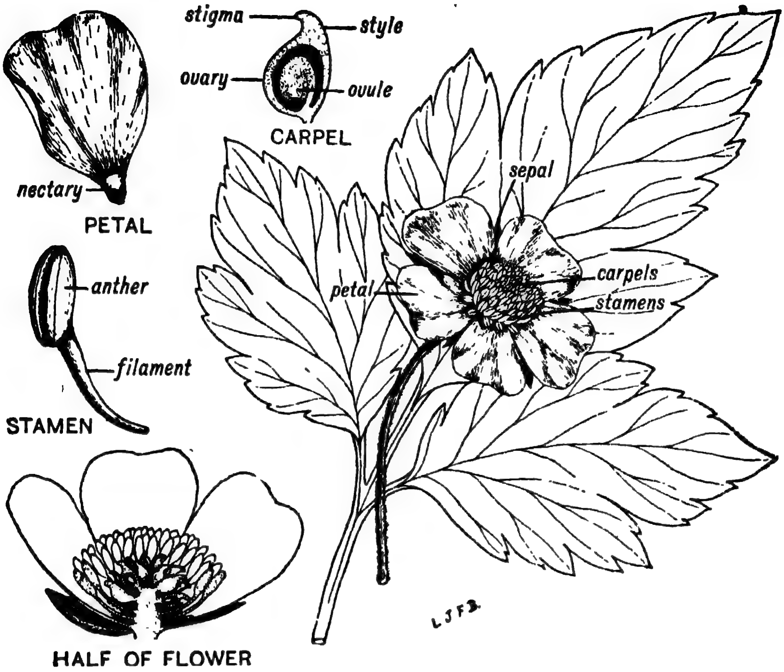


FIG. 202. FLOWER OF BUTTERCUP.

much sought after by insects. The calyx and the corolla together are known as the **perianth.**

Inside the perianth are a large number of **stamens.** Each stamen consists of a filament with a yellow swelling, the **anther,** at the top. On the anther there is a yellow dust of tiny particles called **pollen grains.** Often when walking through a field of buttercups, the shoes get covered with this yellow dust.

In the centre of the flower are a number of rounded objects, the **carpels,** with spikes at the top called **stigmas.** In many flowers the carpels are all in one piece and it is then called the **pistil.** The lower part of the carpel forms the **ovary,** a little

bag-like structure in which the **ovule** develops into the seed, after it has been fertilised. The part of the carpel between the ovary and the stigma is called the **style** (Fig. 202).

The essential parts of the flower for reproductive purposes are the *stamens* and the *carpels*, for the former bear the pollen containing the male cells, while the latter contain the female cells of the ovules, and protect the seed formed after fertilisation. From what has already been said about reproduction, it is obvious that new seeds can only be formed if the male and female cells unite, that is, if the male gametes reach the ovules. The way in which this occurs is by pollen grains falling on the stigma. They do not then themselves travel down the carpel to the ovary, but instead they produce a delicate tube which grows down the style into the ovary, and the active male gametes pass down this pollen tube and fuse with the female cells of the ovules ; the latter are then fertilised, and each ovule develops into a seed.

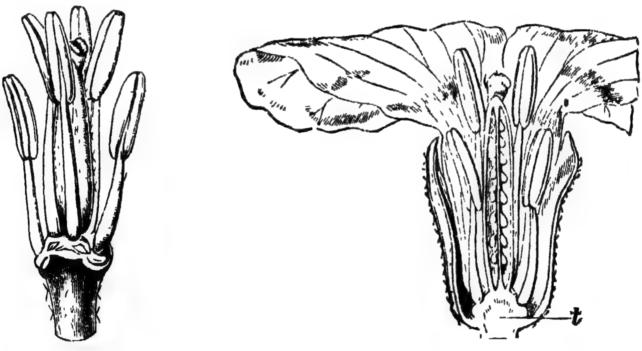
Pollination. The process by which the pollen passes from the stamens to the stigma is called **pollination.** In the case of hermaphrodite flowers (that is, flowers which are both male and female) the stigma may receive pollen from the same flower ; this is known as **self-pollination.** The method is not a good one, for in many cases it results in weak and unhealthy seeds ; many flowers prevent it happening by their stamens ripening before the pistil, so that, even if pollen does fall on the stigma of the same flower, fertilisation does not occur because the ovules are not ready for it.

Better seeds and finer plants are more often obtained by **cross-pollination,** that is, by the method of the pollen from one flower reaching the stigma of *another* flower of the same kind. For this to take place, the pollen may be blown by the wind, or it may be conveyed by insects like bees, wasps, butterflies, moths, flies and beetles. These insects visit flowers in order to obtain the sweet-tasting nectar ; the pollen is then dusted off on to their backs or legs, and they carry it to the next flower

they visit, where it gets rubbed off on to the stigma. Flowers depending on insects for cross-pollination develop all kinds of ingenious devices for attracting them, and generally they make themselves conspicuous by their scent or their bright colour. The tobacco plant, for example, which relies on moths for pollination, emits a pleasant smell at night, when moths are most likely to be flying about. Often the arrangement of the stamens and carpels help to ensure pollination ; a difference in the stamens of the wallflower illustrates this.

The wallflower. When a wallflower is examined, the six stamens are seen to be of different lengths, there being four long ones and two short ones (Fig. 203 (i)). The nectaries, instead of being at the base of the petals as in the buttercup, are at the base of the two shorter stamens. When, therefore, a bee pushes its tongue down to reach the honey, its back gets dusted with pollen from the longer stamens and it carries this to the next flower it visits.

It should also be noted that when a section is cut through the wallflower, a number of ovules can be counted in the ovary



(i) (ii)

FIG. 203. (i) THE PISTIL AND STAMENS OF FLOWER OF WALLFLOWER, THE PETALS HAVING BEEN REMOVED.

(ii) VERTICAL SECTION THROUGH FLOWER OF WALLFLOWER (enlarged). (After Oliver.)

(Fig. 203 (ii)), whereas in the buttercup, the ovary of each carpel contains one ovule only.

Other flowers. A study of the buttercup and wallflower shows differences in the structure of their four different parts, the calyx, the corolla, the stamens and the carpels. Other flowers like the wild rose, the daffodil, and the cherry should also be examined. In all cases enlarged drawings of the various parts, like those shown in Figs. 202 and 203, should be made.

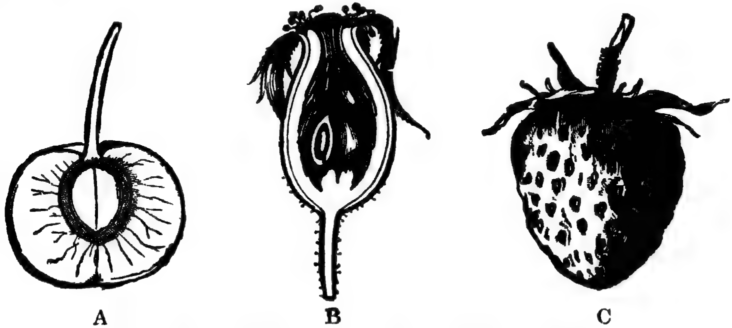


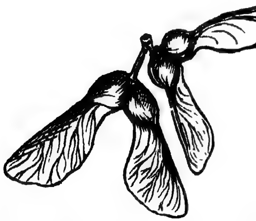
Fig. 204. Fruits with Bird-dispersed Seeds.
A. Cherry. B. Rose. C. Strawberry.

Fruits and seeds. After fertilisation, the petals, stamens, style and stigma of the flower die, while the walls of the ovary grow with the seed and develop into a fruit. The fruit should not be confused with the seeds ; it is the structure and the seeds which it *contains*. Thus it may be a pod, as in the case of the pea and bean, or it may be a fleshy fruit like the plum and the cherry. The walls of the fruit serve to protect the seeds while they are developing, and it helps them to become dispersed when they are ripe. An interesting fruit is that of the strawberry. The actual fruit is the small grain, of which there are many, borne on the swollen, red, succulent portion. The so-called strawberry " fruit " is actually the swollen receptacle bearing many small real fruits.

One method of seed dispersal is the scattering of seeds by birds and animals. Ripe fruits like the raspberry, the cherry and the plum are conspicuous in colour; they are also sweet and juicy. These characteristics make them attractive to birds and animals, so they get carried off and eaten, while the dropped seeds get scattered far and wide (Fig. 204). Other fruits are dispersed by animals because they develop hooks which get entangled in the feathers or hair of the animals; in this way the seeds get transported to a new place.

Fig. 205. "Clock" of Dandelion Fruits. ($\times \frac{2}{3}$)

Another method of seed dispersal is by the means of the wind. The "clock" of the dandelion (Fig. 205) is specially adapted for this purpose; each little tuft of white hairs blown off by the wind carries a seed at the bottom. Fruits of trees, like the sycamore (Fig. 206), the ash and the elm, have winged fruits, which travel some distance with the wind before they drop to earth.



$\frac{1}{2}$

Fig. 206. Winged Sycamore Fruits. ($\times \frac{1}{2}$)

Some fruits disperse their seeds in an explosive kind of way. The pods of gorse seeds curl up and burst with a sharp crack, shooting out their seeds on to the surrounding soil. Violets and pansies shoot out their seeds in a similar kind of way.

Many of the seeds produced by a flower do not encounter suitable conditions for them to germinate and develop into new plants, but those that do, carry on the race of the flowering plant.

CHAPTER XIX

FLOWERLESS PLANTS

Development of plant life. Although flowering plants seem to be more familiar to us than flowerless ones, they are actually less numerous. The majority of the plants growing on the surface of the earth do not produce flowers, and it is only the more highly developed forms of plant life that bear flowers and reproduce themselves by means of seeds. In the process of evolution, there seems to have been a gradual transition from plants of a simple structure to ones that are more complex; there is, moreover, reason to believe that all types of life—both plant and animal—began as very simple organisms existing in the sea and inland lakes. After millions of years, these organisms became more complex and invaded the land. We should expect, therefore, that the more primitive types of plants would grow in water, and the most simple flowerless plants, like green scum and the various kinds of sea-weeds, are all to be found in watery places.

Types of flowerless plants. There are three main groups of flowerless plants, the **Thallophyta**, the **Bryophyta** and the **Pteridophyta**. All of them have other means of reproducing themselves than by seeds; it was seen in Chapter XVIII that flowers are necessary for the production of seeds.

The Thallophyta are plants with a comparatively simple structure. To this group belong the **algae**, like Spirogyra and sea-weed, the **fungi**, like mushrooms, moulds and yeast, and the **bacteria**. An important difference between the algae and the other two types is that algae are *green* plants and possess chlorophyll; they

can therefore use the energy of the sunlight to build up their supplies of food (photosynthesis) in a similar way to the green plants already described. Fungi and bacteria are destitute of chlorophyll and are often colourless; they depend for their food on other plants, or even on animals, dead or alive.

To the Bryophyta group belong the various kinds of mosses and liverworts; they are green plants generally to be found in damp places and in fresh water. Their structure is more complicated than that of the Thallophyta, and the mosses have a definite stem and leaf structure.

The most highly developed group of flowerless plants are the Pteridophyta; their structure is sufficiently complicated for them to be akin to flowering plants except, of course, that they do not bear flowers. The different kinds of ferns all belong to this group.

Fig. 207 shows examples of flowerless plants, belonging to each of these three groups.

Protococcus. One of the simplest of the plants belonging to the Thallophyta group is *Protococcus*, a green powdery growth to be seen everywhere on tree trunks and on palings. It requires a good supply of water, so it generally grows on the damper side of a tree trunk, that is, the windward side, where the wind and rain beat on the tree. Millions of this tiny plant make up the green crust that is visible, for each one consists of a single protoplasmic cell about $\frac{1}{2000}$ of an inch in diameter. In spite of its smallness, *Protococcus* feeds, like other green plants, on rainwater and the carbon dioxide it absorbs from the atmosphere, as well as on mineral matter in the dust around it. Nourished in this way, it grows to its full size and then reproduces itself in the simplest possible way—by the method of fission described in Chapter XVII. Thus each cell divides and is converted into two, until ultimately millions of plants have developed from one parent.

Spirogyra. Another simple plant in the algae group is found as a green scum on the surface of ponds. Most of the scum that

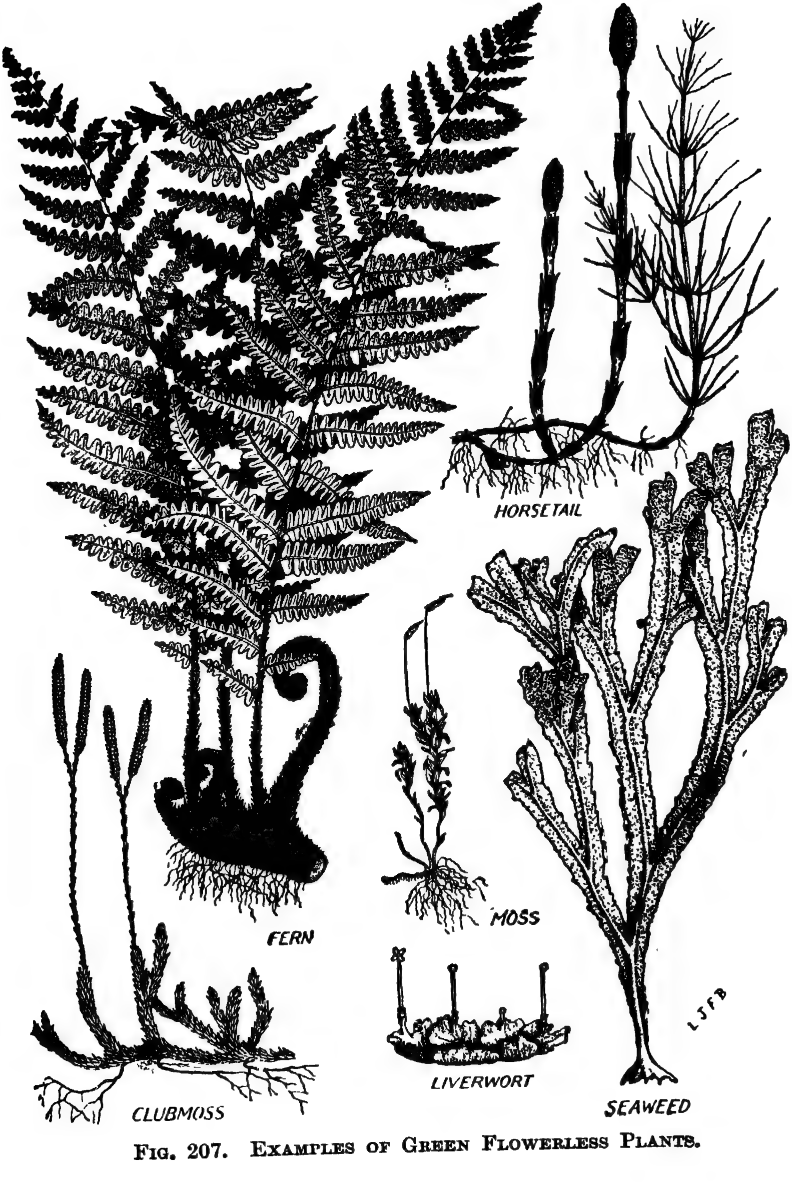


FIG. 207. EXAMPLES OF GREEN FLOWERLESS PLANTS.

can be seen consists of green thread-like filaments of *Spirogyra*. When highly magnified (Fig. 208) each filament appears as spiral coils of green matter ; these are chloroplasts, that is, tiny protoplasmic bodies containing chlorophyll. Thus the plant has a bright green colour and feeds like other green plants, except that it has no stomata and exchanges gases with the air and water outside directly from the protoplasm through its cell walls. The protoplasm lining the cell walls is called the **cytoplasm,** and within this is a vacuole or cavity containing cell-sap. Close to the cytoplasm is the **nucleus** of the cell.

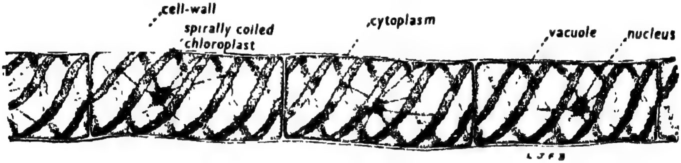


FIG. 208. *Spirogyra*, A THALLOPHYTE. (× 110)

Nearly all plant and animal cells contain a nucleus ; it is generally situated in the centre of the cell and governs all processes which take place in it. When new cells are formed the nucleus divides into two, and half the protoplasm goes with each part, while new cell walls grow round each of the new cells.

Spirogyra reproduces itself in a more developed way than *Protococcus* does, by a simple kind of sexual reproduction. The gametes of two plants may be exactly similar, but the more active gametes which move can be called male ones, and those which await them, female ones. By their fusion, zygotes are formed. For reproduction to take place, two *Spirogyra* plants arrange themselves with their filaments parallel and tubes develop connecting the cells of one filament with the cells of the other filament. A gamete formed by a cell of one filament wriggles along the completed connecting tube and fuses with the gamete in a cell of the plant at the other end of the tube.

The zygote so formed then escapes and can then grow into a new *Spirogyra* plant.

Sea-weed. A familiar sight on the seashore is **sea-weed**; some kinds are green, some brown and some red. Green sea-weed generally grows in very shallow water, and is often left exposed on rocks. Brown sea-weed is a very common variety, which also grows in shallow water, and is left uncovered when the tide goes down. Red sea-weed is less familiar as it generally grows in quite deep water. In spite of these differences of colour, all these sea-weeds contain chlorophyll and are nourished like green plants, but in the case of the brown and red varieties the green colouring is partly obscured by the brown or red colouring matter present. Often little floats containing air grow on the plant; these help to keep it near the surface of the water, where there is plenty of the light and air it requires to build up its food supply.

Although a typical sea-weed like **sea-wrack** (Fig. 209) seems to have something like a root, stem and leaf structure, actually it has none of these organs, because its various parts are of different development and structure. Its broad leaf-like part is called the **thallus**; this is flattened and branched and has a thickened rib down the middle. The lower end of this rib is more like a stem, and at the base of it is a disc by means of which the plant attaches itself to rocks. At the ends of the branches of the thallus little yellow spots can be seen. These spots mark the openings of little pockets in which male and female gametes are formed. At the right stage in their development, the sea-weed sheds the gametes into the sea, and it is there that fertilisation takes

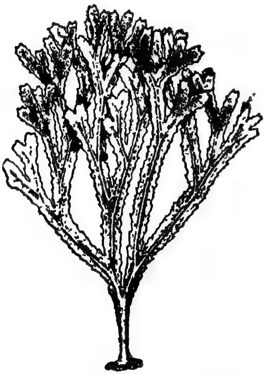


FIG. 209. THE *Sea Wrack* A THALLOPHYTE. (After Thompson.) ($\frac{1}{16}$ natural size)

place. The smaller and more active male gametes surround a larger female one, and one of them fuses with it, so that a zygote is formed.

Fungi. Fig. 210 shows some of the familiar flowerless plants that are classed as fungi. They are essentially different from the algae in that they possess no chlorophyll, and can live equally well in the dark or in the light. They nourish themselves, not by photosynthesis, but by living on other plants, living or dead, or on animals. The potato blight, for example, feeds on the living potato and causes disease ; the pin-mould grows on decaying plant material such as damp bread. A larger type of fungus than the various moulds are plants like mushrooms and truffles, which are useful to man for food. Truffles are a delicacy better known on the Continent than in this country ; they grow beneath the ground, and pigs are used to locate them by smell. A great many fungi are extremely poisonous ; toadstools are of this type, and unfortunate accidents sometimes occur through people confusing them with mushrooms.

The mushroom. Mushrooms can be found growing in the fields after damp weather in the summer and the autumn ; they grow so rapidly that often they spring up in a night. The best soil for them is that which is rich in the decaying remains of plants and animals. They obtain nutrition from these substances by a network of fine threads beneath the ground (the vegetative part in Fig. 210). These **hyphae**, as they are called, continue more closely packed together into the stem and cap.

The edible part of the mushroom is the plant's means of reproduction. On the undersurface of the cap are a number of radiating dark brown plates or **gills**, and when the mushroom head is placed gills downwards on a sheet of paper, brown markings are produced. These markings consist of tiny brown specks called **spores** ; from them new mushroom plants can be grown. Spores are formed by *asexual* reproduction as defined in Chapter XVII. They are *single* cells capable of

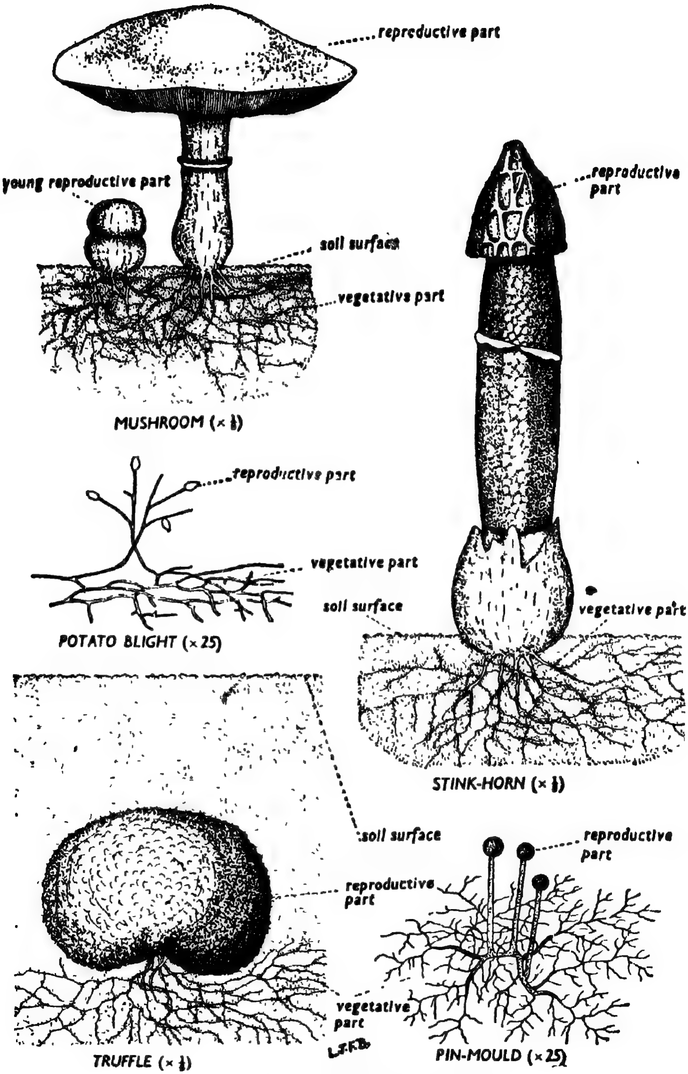


Fig. 210. Types of Fungi.

developing into a new plant, and are not of the same nature as seeds; the latter may consist of thousands of cells, and are *always* formed by sexual reproduction. The pin-mould and many other fungi reproduce themselves in a similar way by spores; but the pin-mould and other fungi have a sexual method of reproduction *also*.

Bacteria. Somewhat similar to fungi, are the extremely minute single-celled plants known as **bacteria.** They are so very small that they are not visible with the naked eye, many of them being little more than $\frac{1}{1000}$ of a millimetre in length. Fig. 211 shows various kinds of bacteria magnified 1500 times. They can be seen to be of different shapes; the spherical ones are called **cocci**; the ones like short rods, **bacilli,** and the spirally twisted ones, **spirilla.** The first two types are the more common; for example, pneumococci are the bacteria causing pneumonia, and the diphtheria bacilli cause diphtheria. Often bacteria have one or more slender protoplasmic threads projecting from them (Fig. 211) and they use these **flagella** to swim about in liquids like blood or the saliva. Since they possess no chlorophyll, they rely for nutrition on plants and animals, either living or dead. Numerous bacteria feed on animals products, like milk and meat, on plants and decaying matter in the soil, and many live in the human body in the saliva and the intestines

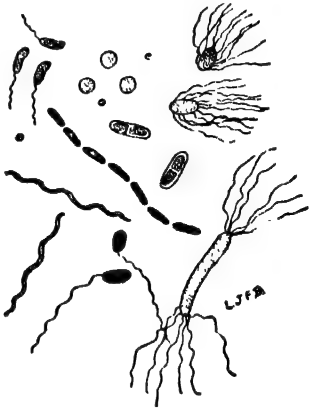


FIG. 211. TYPES OF BACTERIA. (× 1500)

All bacteria are not harmful and some are definitely useful, as, for example, the nitrifying and denitrifying bacteria of the soil mentioned in Chapter XVI. Other useful varieties are those which are active in butter-making and cheese-making,

and in the purification of sewage at sewage works. The air always contains many bacteria, and some of these are the harmful ones, causing disease; this fact was discussed in Chapter V. Certain diseases like typhoid, cholera and tuberculosis are caused by drinking polluted water or milk, in which harmful bacteria are present, but the majority of diseases are due to the bacteria present in air, soil, and in the blood of the infected person. It has already been seen that bacteria reproduce themselves by fission, so that they multiply at a tremendous rate. Those causing disease, therefore, flourish and increase once they have entered the blood, because they find in it ideal conditions of warmth, darkness and a good supply of food. The waste products formed by bacteria are called **toxins**, and when bacteria are multiplying in the human body, the presence of toxins soon causes a rise of temperature and makes a patient ill. The way in which the body combats such infection will be described in Chapter XXII; the value of antiseptics and disinfectants has already been discussed in Chapter XVI.

The Bryophyta. All the flowerless plants so far considered belong to the Thallophyta group. The plants of this group are simple in structure and possess only a thallus, that is, a body not divided into root, stem and leaves. The next group, the Bryophyta, consists of more highly developed plants, the mosses and the liverworts; the mosses have a definite stem and leaf structure, and the liverworts, although consisting of merely a thallus, reproduce themselves like the mosses, by a method of both sexual and asexual reproduction.

Mosses. A moss like the common moss (Fig. 207) has a stalk and leaves, and strands called **rhizoids** growing at the lower end of its stalk. The word *rhizoid* means "like a root"; the strands are not considered to be true roots, because they differ from them in certain important respects, although much of the work they do is the same. Thus a moss uses its rhizoids to fix itself in the soil, and to absorb water and mineral salts from it.

In addition, it obtains nutrition from the air like other green plants.

Reproduction takes place by alternate sexual and asexual processes. Tiny structures in the leaves produce both male and female gametes, but fertilisation can only take place under water. When, therefore, there has been a heavy fall of rain or dew, the spermatozoids (or male gametes) swim through the moisture to the eggs (or female gametes) and fertilise them. The zygote so formed does not develop into a new plant, but into a spore-producing organ. A long stalk shoots up, bearing a capsule at its end, and when the capsule ripens, it produces tiny brown spores. On a dry day, a capsule opens, and the spores fall to the ground. If the soil is suitable, new moss plants may then grow from the spores. In this way, reproduction is achieved by gametes being produced *alternately* with spores.

Liverworts. Liverworts get their name from their shape, and because they used to be considered a remedy for ailments of the liver. They always grow in ditches and damp places, and sometimes they are to be found growing actually under the water. A typical liverwort like *Pellia* (Fig. 207) consists of a flattened green thallus with a thickening to form the mid-rib; whitish rhizoids grow from the undersurface of the thallus and serve the same purpose as those of the moss plant.

Its method of reproduction is similar to that of the moss plant. Sperms are produced in special organs near the mid-rib on the upper surface of the thallus, and eggs in certain organs near the points of branches of the thallus. Again rain-water or dew is necessary for fertilisation; when the thallus is covered with moisture, the spermatozoids swim to the organs containing the eggs. The zygote formed develops into a spore-producing organ, consisting generally of a white stalk, bearing a black capsule at its end. Spores are formed in the capsule and when they are ripe it splits, and they are ejected. Their escape is assisted by the action of certain cell elements called **elaters**;

the latter vary in shape with the moistness of the surrounding air, and in dry weather help to eject the spores. From the spores new liverwort plants are formed.

In the case of both the moss and the liverwort, the zygote really develops into a different kind of plant consisting of a stalk and capsule. This can be described as being **parasitic** on the original plant. Thus in the life-history of the moss and the liverwort there is an **alternation of generations** of a gamete-producing plant and a spore-producing one.

Ferns. The different kinds of ferns to be found everywhere belong to a third group, the Pteridophyta. The plants of this group are the most highly developed of the flowerless plants and resemble flowering ones, except that they never bear flowers. They have a definite root, stem and leaf structure, and different types vary considerably in size and appearance. Where the vegetation is tropical, ferns may grow as big as trees. In Fig. 207, the club-moss (which is not a true moss), the horse-tail, and the fern all belong to this group.

The common fern as shown in Fig. 207 has a massive rhizome with many adventitious roots growing from it. It was seen in Chapter XVIII that plants with rhizomes can be reproduced by vegetative reproduction and this frequently occurs with the fern plant. Its true method of reproduction, however, involves an alternation of generations like that occurring in the mosses, with the important difference that the plant with which we are most familiar is the *spore-producing* one ; in the mosses the main plant is the one producing gametes.

If the leaves of a fern are carefully examined, some will be found to have brown knobs on the back of them. These contain spores, which can be shaken off the leaves in the form of a brown dust. All the leaves of a fern are not of this type ; those which do not produce spores are used for the physiological processes of transpiration, respiration and nutrition only. In dry weather, the spores are ejected ; many die but those that survive germinate to produce organisms which bear gametes.

For germination, the spore requires plenty of moisture and shade; under such conditions it develops into a tiny flat heart-shaped structure called a **prothallus** (Fig. 212). This little plant grows rhizoids and possesses chlorophyll, so that it can nourish itself in the usual way by absorbing water, carbon dioxide, and mineral salts. Moreover, on its damp undersurface it produces spermatozoids and eggs. These gametes, like those of other plants considered in this chapter, can only unite if water is present, so the best position for a prothallus is in a damp and shady place. When there is a film of moisture on the undersurface the spermatozoid can swim to the egg and fuse with it. The zygote so formed develops into an ordinary fern (a sporophyte) and this, when mature, produces spores. In this manner, the cycle continues; such an alternation of generations is an essential feature of the life of both ferns and mosses.

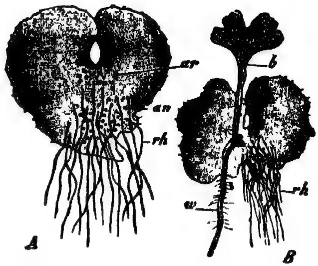


Fig. 212. Fern Prothallus.

A. Prothallus seen from below; *an*, male organs; *ar*, female organs; *rh*, hairs. B. Prothallus with young sporophyte attached to it; *b*, the first leaf; *w*, the primary root. (About 5 times natural size)

At the beginning of this chapter, mention was made of the fact that all the earlier forms of plant and animal life seem to have appeared first in the water. This statement appears more true now that it has been realised that most of the less highly developed forms of plant life, the green flowerless plants, require wet conditions for the process of reproduction.

CHAPTER XX

LIFE-HISTORY AND STRUCTURE OF AMOEBA, HYDRA, WORM AND INSECT

Animal life. Much of our interest in our environment is due to the living animals we encounter ; there are such familiar creatures as bees, butterflies, birds, cats, dogs as well as the most highly developed animals of all—other human beings. All animals can be divided up according to their structure into two classes ; those which do not possess backbones are called **invertebrates,** and those which have backbones are known as **vertebrates.** Thus insects and worms are examples of invertebrates, and birds, frogs, fishes, dogs and men of vertebrates. The present chapter deals with the simpler forms of animal life, and these belong to the invertebrate class. Just as plant life began in the water and gradually evolved into more complicated and beautiful types like the various flowering plants, so animal life began under water with small specks of protoplasmic material somewhat like the present-day amoeba. It is even probable that both plant and animal life originated from the *same* simple organisms, although these later diverged into the different types of living matter. With the process of evolution through millions of years, vertebrate animals followed invertebrate ones until finally man himself appeared, and showed his superiority over other animals by his unique qualities of mind and spirit.

The amoeba. The amoeba is a tiny animal that lives in stagnant pools and in moist soil. Some of the larger ones are just visible with the naked eye as tiny white specks, but most

of them are only about $\frac{1}{200}$ of an inch in diameter, and it is necessary to study them under the microscope. Fig. 213 shows the appearance of an amoeba when magnified 600 times.

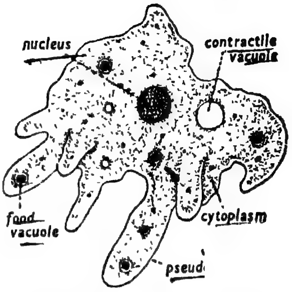


FIG. 213. AN AMOEBA. (× 600)

It can be seen to consist of an irregularly shaped mass of colourless jelly-like protoplasm. A small rounded body rather darker than the rest is the **nucleus.** It was mentioned in Chapter XIX that all cells have a nucleus, and the amoeba, consisting of a single protoplasmic cell, has the one central nucleus. The rest of the protoplasm surrounding the nucleus is called the **cytoplasm** ; this looks clear at the edges, and granular and less transparent towards the interior. In it there may be greenish and brownish specks, which are the tiny plants the animal has absorbed, and which it is digesting.

Probably while the amoeba is being observed under the microscope its shape will be continually varying, and it may move out of the range of vision. This occurs because the little creature puts out bulges called **pseudopodia** or " false feet ". By means of these it is able to crawl or flow in a certain direction. The various pseudopodia are only temporary, and the bulges on one side may disappear, and others form in a different part of the cytoplasm. so that the amoeba may move in another direction. The pseudopodia are also used to surround and engulf the tiny plant organisms required for food. These are taken into the cytoplasm together with a drop of water and form a **food-vacuole** (Fig. 213). Thence the food is absorbed into the protoplasm by a digestive process, and any undigested remains are cast out and left behind when the amoeba flows away from them. Thus the animal digests food without having any special organs for the purpose as the higher animals have.

Similarly it breathes—without having any gills or lungs—by taking in oxygen all over its body. It obtains this from the water in which it lives, and, as is usual in respiration, gives out carbon dioxide.

In addition to food vacuoles, another space, the **contractile vacuole,** may be observed. This consists of a drop of liquid which increases in size until it gets almost as big as the nucleus and finally collapses. It then starts again and gradually fills up until once more it has reached the size at which it collapses. The liquid in it is water containing waste products, which are thrown out with the water when enough has accumulated.

The amoeba, then, seems to have simple methods of nutrition, respiration and excretion. In addition it reproduces itself by the simplest possible method—that of fission. When it has absorbed sufficient food to grow to its maximum size, the nucleus begins to divide in two by becoming like a dumb-bell in shape. The cytoplasm then changes similarly and two amoebae separate out from the original one, each consisting of half the parent nucleus and half the parent cytoplasm. In this way it seems almost as if the amoeba is immortal, because although one individual disappears, the material of which it is made remains alive in its two descendants.

The various kinds of cells which make up the tissues of living animals are all similar fundamentally to the single cell that forms the amoeba.

The hydra. Another animal of simple structure that exists in fresh water is the **hydra.** It is given this name because, when cut up into pieces, each piece can grow into a complete hydra again, so that it is very like the animal Hercules had difficulty in killing.

The hydra is a little brown or green animal, a quarter of an inch or less in length. Generally it is tubular in shape, but it can shorten and bend itself and, when disturbed, may contract until it is almost spherical (Fig. 214). It clings with its base to float-

ing duckweed or twigs in fresh-water pools, and feeds on the tiny insects and plants living in the water round it. It captures these with its waving **tentacles**, and the latter waft this food into its interior through the mouth which is in the midst of them. The tentacles are also used by the hydra for swimming through the water, and for helping it to change its position on its support.

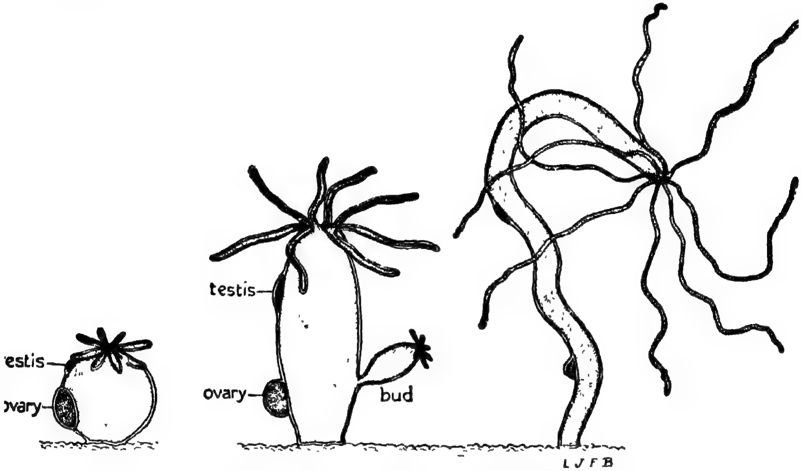


FIG. 214. DIFFERENT SHAPES OF A HYDRA.

This little animal can be seen with the naked eye, but a microscope is necessary for studying its structure. Fig. 215 shows the appearance of a longitudinal section of a hydra magnified 30 times. The tubular body can then be seen to consist of an outer layer of cells, the **ectoderm**, and an inner layer, the **endoderm.** Between the two is some gelatinous material, the **mesogloea.** Certain of the ectoderm cells, particularly some of those on the tentacles, have a curious property of shooting out a poison thread when anything bumps against them. Thus a small insect like a water-flea may be stunned and poisoned when it blunders against such a cell, and the tentacles then waft

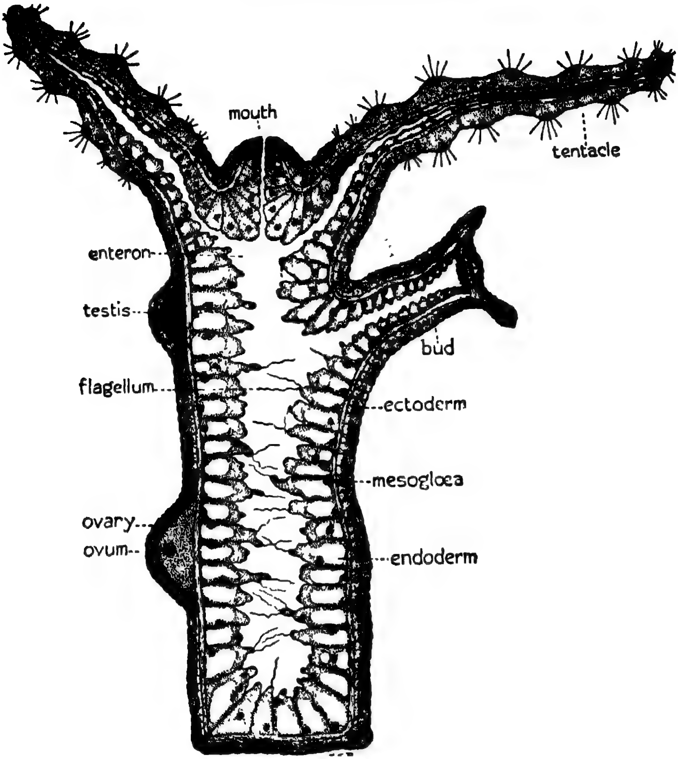


FIG. 215. HYDRA. (×30)

it in through the mouth of the hydra for it to be digested by the cells of the endoderm. The latter can put out tiny protoplasmic threads called **flagella** which move to and fro and cause a current of water to circulate through the inside of the hydra; this moving water carries any undigested food back through the mouth again. Thus the body of this animal is very simple in structure, and one aperture serves both for nutrition and excretion. Respiration takes place, as in the amoeba, without any special respiratory organ. Oxygen dissolved in the pond

water is absorbed through the general surface of the animal, and carbon dioxide is passed out in a similar way.

The hydra has two methods of reproduction, (1) by budding, (2) by sexual reproduction. The first method is generally used when the animal has an abundant food supply and is well nourished. Little knobs appear on the side (Figs. 214 and 215), and these grow until they have formed young hydra, which swim away and settle down somewhere else, or if a hydra is cut into pieces each piece may grow into a complete hydra. This type of asexual reproduction is very like the vegetative reproduction of plants. When food is less abundant, the hydra may use a method of sexual reproduction, but as it is hermaphrodite, both male and female gametes occur on the same animal. A bulge may grow in the ectoderm at the lower end of the hydra; this is the ovary containing the egg or ovum (Fig. 215). Higher up nearer the tentacles another bulge forms; this is the **testis** and it contains a number of male gametes or **spermatozoa.** Each of the latter consists of nucleus with a tail (or flagellum) of cytoplasm attached to it. When the ovary and testis are ripe they burst; the spermatozoa can swim about in the water by lashing their flagella, and one may reach the ovum and fuse with it to form a zygote from which a new hydra can develop.

Sea-anemones. Sea-anemones (Fig. 216) are brightly coloured sea-animals, which are very similar to the fresh-water hydra. They cling to rocks on the seashore and, like the hydra, are surmounted by tentacles which surround a mouth opening into their interior. The jelly-fish is also a closely related animal.

Earthworms. One of the most common animals in the earth is the ordinary **earthworm**; it has been estimated that as many as 80,000 of them may be present in one acre of ground.

The earthworm is tubular in shape, its body being divided up into about 150 segments (Fig. 217). Its front end is pointed

and contains an opening which serves as a mouth, and at its other end is a slightly flattened tail. It has no eyes or ears, but it can distinguish between light and darkness, and it is sensitive to vibrations of the ground. It has a simple nervous system and a primitive brain which controls its movements. Thus in the daytime it generally stays in its hole in the soil, while at night it emerges in search of food ; at such times it usually leaves

FIG. 216. A SEA-ANEMONE.

its flattened tail just inside its hole, so that it has a good grip of it, and can retreat quickly if it becomes aware of danger approaching.

EXPT. 93. **A study of the movements of earthworms.** Take a large glass jam jar and nearly fill it with several different coloured layers of soil, putting a layer of gravel at the bottom to keep the soils well drained. Stick a strip of paper on the side to mark the positions of the various layers. Place several earthworms on the surface of the soils together with some leaves, and place a piece of glass on top. Now cover the whole with a black cloth ; if this is not done, the worms will retreat to the middle of the jar, because they do not like the light. When the black cloth is in place, probably several

holes will be made along the sides of the glass, where they may be seen.

In this way the behaviour of the worm in its hole may be studied. After some time, it will be noticed that the layers of soil have become indistinguishable as a result of the movements and behaviour of the worms.

A worm should also be made to crawl along a sheet of paper and its mode of locomotion studied.

The earthworm moves by shortening and lengthening its body and by putting out stiff hairs called **setae.** These can be

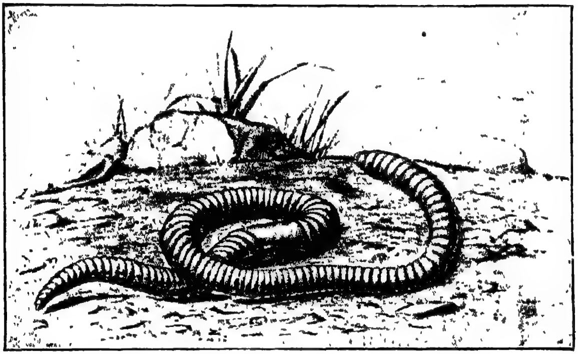


FIG. 217. AN EARTHWORM.

heard brushing against the paper as it moves. There are four pairs of setae on each segment, and the worm fixes the setae of its back portion in the surface while it reaches out in front, and then fixes the setae of its front portion while it draws its tail up. When passing *through* the soil, it not only uses this method, but also actually *eats* the soil. It swallows large quantities of it, obtains nutrition from the decaying organic matter therein, and then lets the undigested remains pass out of its lower end through the **anus.** These remains are left on the surface of the ground near its hole in the form of worm castings. In addition to soil, it also feeds on leaves, which it often draws into the mouth of its hole. Thus in its method of nutrition

and excretion, the earthworm is really a friend of man, because it keeps the soil aerated and well mixed; fresh soil from 4 ft. to 6 ft. down may be brought to the surface, and the worm is like a natural plough.

Excretion of undigested soil through the anus is not the worm's only method of removing waste matter. It has also a pair of fine tubes called **nephridia** in nearly every segment, and these excrete water and nitrogenous waste matter; they correspond to the kidneys of higher animals. A further advance in structure over simple animals like the hydra is that the earthworm has a simple but distinct system of blood vessels on the inner surface of the wall of its body. It has, however, no respiratory organs, and breathes by taking in oxygen and giving out carbon dioxide through the general surface of its body.

Like the hydra, the earthworm is hermaphrodite, but no worm fertilises its own eggs. It passes its spermatozoa into special receptacles in the front part of the body of *another* worm. This worm then uses them to fertilise its eggs in the following manner. It makes a round cocoon from material discharged by the clitellum (the thickened part in Fig. 217), and lays eggs in it. To free itself from the cocoon the worm wriggles backwards, and as the sperm receptacles move past the cocoon the spermatozoa are forced out into it. The worm then slips its head right out of the cocoon, leaving the spermatozoa to fertilise the eggs in it. Thus fertilisation takes place outside the body of the worm altogether. Generally only one worm develops from each cocoon.

Arthropods. Only a few simple invertebrate animals have so far been studied. More advanced types have a more complicated structure and a very large group, called the **Arthropods**, have a segmented body, jointed limbs, and more definite organs than the simpler forms of life. To this class belong the **Crustacea**, like lobsters, shrimps and crabs, **Myriapoda**, like millipedes and centipedes, **Insecta**, like flies, bees and beetles, and **Arachnida**, like spiders and scorpions. It is impossible, in a

brief study of invertebrate animals, to cover the vast field of all the arthropods ; in the insect group alone as many as 500,000 different kinds of insects are known to scientists. Since, however, this is the largest of all the groups of animals, and contains some of the creatures with which we are most familiar, a few common insects will be considered next.

Insects. Insects differ from other arthropods in that they all have six legs. Furthermore, most of them can fly, and possess one pair, often two pairs, of wings. The legs and wings are borne by a middle part of the body called the **thorax** (Fig. 218). At the upper end of the thorax is the head, in which there are eyes and jaws and a pair of feelers (or **antennae**). At the lower end of the thorax, the **abdomen** is attached, and the complete digestive system consists of a mouth, stomach and intestine. Most insects show a high degree of intelligence in their behaviour, and seem to possess a nervous system corresponding to a much more developed brain than the primitive one of the earthworm ; this is particularly true of insects like ants and bees, which live in social communities.

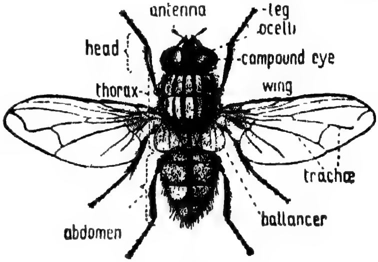


FIG. 218. A HOUSE FLY.
By courtesy of the Director of the British Museum (Natural History)

The house fly. The ordinary house fly is a source of great danger in the home, because it spreads disease by carrying bacteria and dirt from manure and refuse heaps to human food. In this way, summer diarrhoea may be caused in babies and small children. Other diseases. like cholera, typhoid fever and dysentery, are also carried by flies. It is important, therefore, that flies should be prevented from breeding, and that all foodstuffs should be kept covered.

Like other typical insects, the body of the house fly consists

of three parts, the head, the thorax and the abdomen. To the thorax, there are attached six legs and two pairs of wings ; one pair of the latter are very small, and are known as balancers. The veins that can be seen in the larger pair of wings are really some of the network of tubes called **tracheae,** by means of which respiration takes place. These tracheae extend all over the body of the fly, and make a connection with the outside air through pores situated between the segments of the body. There is also a simple system of blood circulation controlled by a primitive kind of heart ; this blood is not red like human blood, but is almost colourless.

In the head there is a pair of large **compound eyes** composed of thousands of tiny lenses ; the fly must therefore have a queer kind of multiple vision very unlike our own, and it can see in many directions without moving its head. In addition, it possesses three smaller simple eyes or **ocelli,** and these are placed towards the top of its head. The antennae vary in length with different kinds of flies. From the mouth there hangs a tubular structure, the **proboscis,** by means of which food is sucked up into the mouth.

Flies are not hermaphrodite like the hydra and the earthworm, but are divisible into two sexes, male and female. After fertilisation, the female fly lays tiny white eggs, generally on stable manure or on a rubbish heap ; often one fly may lay over 100 eggs in a day. After a day or two these eggs hatch out into **larvae** or maggots, which feed on the refuse around them. After five days or so, they have grown to their full size—about half an inch, and they then change into motionless **pupae** (Fig. 219). The pupae gradually get darker in colour, and if the weather is fairly warm, in a week or so an **imago** or full-grown new fly emerges. A series of changes such as this—from larva to pupa to imago—is known as **metamorphosis,** and it is an important part of the life-history of other insects besides flies : bees, ants, wasps, butterflies and moths all undergo a metamorphosis.

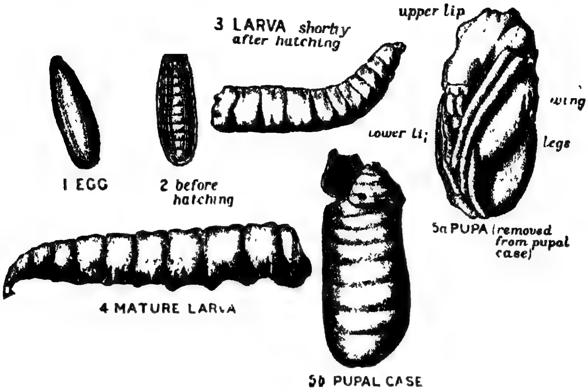


FIG. 219 LIFE-HISTORY OF HOUSE FLY. After Gordon Hewitt. Much enlarged.

Since flies breed in this way on refuse and manure heaps, it is obvious they can easily contaminate human food by the bacteria they bring to it by means of their feet and bodies. It is advisable, therefore, to cover refuse heaps so that they cannot use them for breeding places, and to use fly traps in the home to stop their harmful activities.

Similar types of flies which are also disease carriers are **mosquitoes** and **tsetse** flies. In tropical countries certain types of mosquitoes carry malaria, and certain other types, yellow fever, while the tsetse flies are responsible for sleeping sickness. Daddy-longlegs and fleas also belong to this same group of **Diptera,** that is, insects possessing two wings.

The honey-bee. Mention has already been made of the important work of the honey-bee in the cross-pollination of flowers. In addition, the honey-bee is a most useful insect to man, because of the honey and wax it produces. It makes the honey from an admixture of the nectar from the flowers it visits and its own saliva. It does this with the purpose of storing up a winter supply of food for itself, but the honey is such a palatable foodstuff that human beings annex some of it for themselves.

FIG. 220. HONEY BEE.
Worker (imperfect female), queen (perfect female) and drone (male).

The bee makes a nest or hive for itself in holes in trees or in walls, using materials collected from trees and plants to complete the structure Artificial hives are used by bee-keepers who keep bees for profit. Inside the hive, the bee makes structures consisting of six-sided cells of wax, and this **honeycomb,** as it is called, is used for the development of new bees as well as for storing honey.

A hive is the home of one **queen** bee, several hundred **drones,** and thousands of **workers** (Fig. 220). These different kinds of bees all play their part in serving the community in which they live. Generally only one queen lives in each hive; if others develop there is a fight, which results in the death or ejection of the defeated queen. The queen is always a female of a larger structure and more slender body than the other bees in the hive, and her chief purpose in life is to lay eggs; the others work for her and protect her. The drones are male bees; they are stouter and smaller than the queen, and provide the substance with which she fertilises her eggs. Apart from this, they do nothing and so, at the end of the summer when food is scarce, the lazy drones are often ejected from the hive and left to die. By far the most numerous members of the community are the thousands of busy workers; they are the smallest and most active of all the bees. Some of them make wax and construct the honeycomb, others visit the flowers to collect the nectar from which the honey is formed, while others remain in the hive to look after the young larvae. Those that go from flower to flower suck the liquid nectar from the nectaries by means of

their long proboscis and pass it into their honey bags, where changes take place in it so that it can later be discharged into the cells of the honeycomb in the form of honey. They also collect pollen in a pollen-basket on their hind legs, and both the pollen and the honey serve as food for the whole community.

The queen, the drones and the workers have a similar structure to other insects, and possess bodies consisting of a head, thorax and abdomen, six legs and four wings. The wings are gauzy and transparent, the back pair being smaller than the front (Fig. 221). Both the queen and the workers have a barbed sting at the end of the abdomen, and since the barb prevents its withdrawal once it has been used, the bee, after stinging, has to tear itself away from this organ, and is consequently so mutilated that it generally dies. In any case, a worker bee only has an average life of a few months, although a queen may live three or four years.

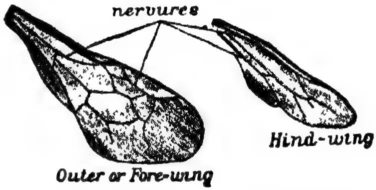


FIG. 221. FORE AND HIND WING OF BEE.

The eggs from which the various bees develop are all laid by the queen bee ; she may lay as many as 3000 in one day. If the eggs are fertilised they may develop into queens or workers ; if unfertilised, into drones. For a queen to be produced, the larva that develops from the fertilised egg must be fed by workers on a special food called the **royal jelly**, and when fully grown, this larva is sealed in a special cell, the royal cell. Workers, drones and queens all develop in special cells in the honeycomb (Fig. 222). The larva spins a cocoon and this becomes a motionless pupa or **chrysalis**. Two or three weeks after the time the egg was laid the imago or perfect bee emerges from the chrysalis. Thus a metamorphosis takes place in the life of a bee as in that of many other insects. Often several new queens develop ; the old queen then leaves the hive, taking with her a

drone and a number of workers, and founds a new colony somewhere else. The new queens cause much disturbance and fighting; all except one are killed or ejected, and the surviving queen becomes the new ruler of the hive.

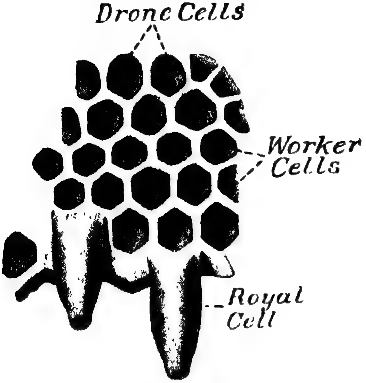


FIG. 222. PIECE OF HONEYCOMB.

There are other types of bees as well as the honey ones, the most familiar being the large bumble-bee. Wasps and hornets are also very similar both in structure and in mode of life. All these insects belong to a group called the **Hymenoptera**; the word means "membrane wing" and the insects of this group are peculiar for their transparent membranous wings. The ants also belong to the Hymenoptera, and they have a highly developed communal life very like that of the bees. All these insects display great intelligence in the way they organise their social life.

Moths and butterflies. One of the beauties of the countryside in the summer is the sight of the gaily coloured **butterflies** that fly from flower to flower in the sunshine. At night, more frequently **moths** appear. A difference between a butterfly and a moth is that the former has antennae with a knob-like ending, whereas the moth has pointed antennae. Furthermore, a butterfly generally places its wings back to back when it alights, while a moth keeps them expanded.

The general structure of moths and butterflies is similar to that of the insects already considered; they have a head, thorax and abdomen, six legs and two pairs of wings. Thei wings are their chief claim to distinction; they are covered with tiny scales of different shapes and colours which give them their unique appearance. For this reason moths and butterflies are

included in a group of insects, the **Hepidoptera,** which means scale-wing. Fig. 223 shows the variety of colour and marking in some typical butterflies, and in a red underwing moth. The difference in the antennae should be noted.

The metamorphosis that takes place in a butterfly can easily be studied.

EXPT. 94. **The development of the cabbage white butterfly.** Obtain some cabbage leaves on which there are clusters of the tiny cream eggs of the cabbage white butterfly. Place them in a large glass jar containing a little water to keep them fresh. In a month, small green caterpillars appear. Supply them with fresh leaves for food, and observe how they shed their skin several times as they grow. When the caterpillar stops feeding notice how it turns into a pupa or chrysalis. It attaches itself to the side of the jar by a sticky pad at its tail end and spins a silk girdle round the other end. It then sheds its larval skin and enters the motionless chrysalis state. Notice finally how the imago or butterfly emerges from the chrysalis.

Fig. 224 shows the appearance of the cabbage white butterfly at different stages in its development. When fully formed, there are differences in size and marking in the male and female insect.

Most butterflies are harmless, but the larvae of the cabbage white butterfly do much damage by their voracious feeding on

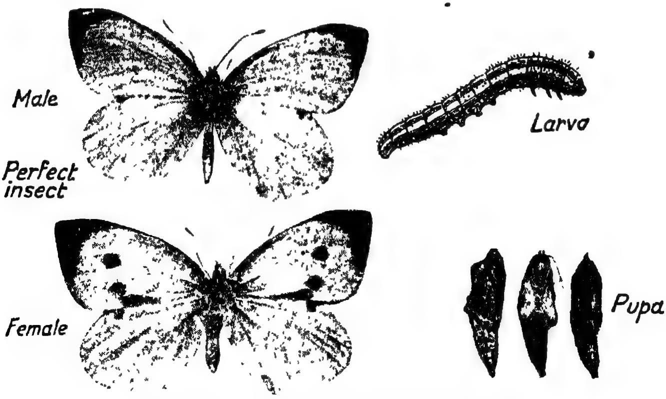


FIG. 224. CABBAGE WHITE BUTTERFLY.

cabbage leaves. The caterpillars of many of the moths destroy crops and vegetation in a similar way. In the home, the **clothes moth** is a source of trouble ; it lays its eggs in fur and woollen garments, and the larvae, when they develop the following spring, use the materials for food and thus eat holes in the garments. The presence of camphor may prevent the moths settling and laying their eggs, or once the eggs have been laid, a thorough beating and shaking of the garments may remove the eggs before they develop. Although most moths are harmful, one kind, the **silkworm moth**, is of service to man. According to tradition, this type came from China, and its larva, when developing into the chrysalis state, spins a cocoon of beautiful silk thread. Where the silkworm is specially bred for obtaining this silk, the chrysalis is killed after the silk has been made and only a few are allowed to develop into moths, which will give a further supply of eggs. Otherwise the silk thread is broken by the moth eating its way out of the cocoon.

From the few invertebrate animals that have been studied in this chapter, it is obvious that the life of man on the earth is very much influenced by the life of the other living creatures around him.

CHAPTER XXI

LIFE-HISTORY AND STRUCTURE OF DOGFISH, FROG AND FOWL

Vertebrates. All animals that have backbones are known as **vertebrates.** A few familiar animals that belong to this class are frogs, sparrows, dogs, sheep, cows, and human beings. The vertebrates possess a skull, which is continuous with a backbone or **vertebral column,** and this structure of bone protects the brain and the nervous system of the spinal cord (Fig. 225). The arrangement of brain and nerves of vertebrates has reached a higher stage of development than in invertebrate animals, and they accordingly show a higher degree of intelligence. In addition, their respiratory systems, their hearts, their systems of blood circulation, and their eyes are all more highly developed than in more primitive creatures.

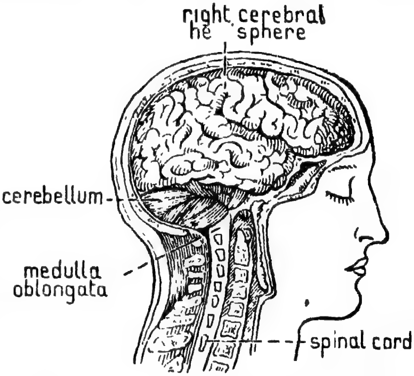


Fig. 225. Section through the Human Brain.
Showing how the skull and vertebral column protect the brain and spinal cord.

Some animals, like fish and reptiles, are said to be cold-blooded, because the temperature of their bodies varies with the temperature of their surroundings, and never differs much from it ; thus they are colder in the winter than in the summer.

Others, like the birds and man himself, are described as warm-blooded, because their blood remains at an almost constant temperature which is higher than that of their environment; thus their blood is as warm in the winter as it is in the summer.

The vertebrates can be divided into five groups:

(1) **Fish** are cold-blooded animals that live in the water; for example, the herring, the cod, the trout. The characteristics of fish are that they are covered with scales; nearly all of them have fins instead of limbs; they respire by means of gills; they lay eggs to produce their young.

(2) **Amphibians** are cold-blooded creatures capable of living in water or on land; for example, the frog and the newt. They are covered with a slimy skin; they possess four limbs; they breathe by gills and by lungs at different stages of their development; they lay eggs from which their young develop.

(3) **Reptiles** are cold-blooded animals which crawl, and which are to be found mostly in warm and tropical climates; for example, the lizard, the snake, the crocodile, the tortoise, and the turtle. Reptiles are covered with a layer of scales; they may possess four limbs terminating in nails or claws, although certain of them, like the snakes and some lizards, possess no limbs at all. They breathe by means of lungs, so that they cannot live under water; generally they reproduce themselves from eggs covered with a shell.

(4) **Birds** are warm-blooded animals that can fly; for example, the hen, the duck, the thrush. All birds are covered with feathers; they possess two legs and two wings; they breathe by means of lungs; they lay eggs contained in a shell.

(5) **Mammals** are warm-bloooded animals that feed their young with milk; for example, the cow, the sheep, the dog. They are covered with hair or wool; they have four limbs; they breathe by means of lungs. They differ from other vertebrates in that, with very few exceptions, they produce young, which when born, are fully formed.

Examples of some of these types of vertebrates form the subject of this chapter. So few reptiles are to be found in Britain, that an example of a reptile will not be included. The **dogfish** will be described as a simple fish, the **frog** as a common amphibian, and the **fowl** as a familiar domestic bird. The highest form of mammal, **man** himself, will be studied in Chapter XXII.

The dogfish lives only in the sea and is very commonly found around the coasts of Britain. It is very like a miniature shark, and, although it is not usually dangerous to man, it is the great enemy of small fish like pilchards, and of small crabs and shellfish.

The dogfish (Fig. 226) is about two feet in length, and its slender streamlined shape enables it to glide through the water very easily. It propels itself along by lashing its tail to and fro ; the powerful muscles it possesses enable it to make this movement. It uses its fins to balance and steer itself up and down through the water in all directions. It has eight fins altogether ; two **dorsal** fins on its back ; two **pectoral** ones near its head, two **pelvic** ones lower down its body, one **ventral** one near its tail and a **caudal** fin on the tail itself.

The fish we generally eat, like the herring, the haddock and the salmon, all have a vertebral column and skeleton of hard bone (Fig. 227). Such bony fish are more highly developed than more primitive ones like the dogfish and the skate. These

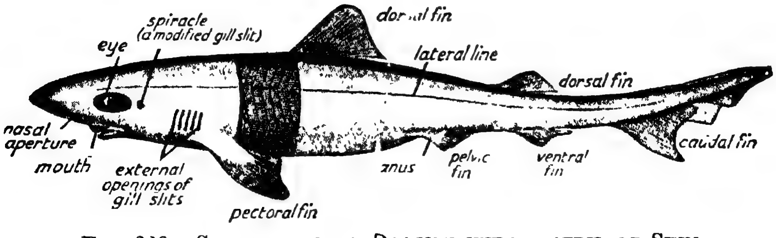


FIG. 226. SIDE-VIEW OF A *DOGFISH* WITH A STRIP OF SKIN REMOVED TO SHOW THE MUSCLES.

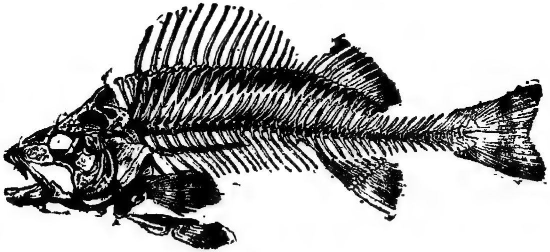


FIG. 227. SKELETON OF A BONY FISH.

simpler fish have a vertebral column and a framework of cartilage and gristle instead of a bony skeleton. They also differ from bony fish in having no flap (or **gill-cover**) over their gills: in Fig. 226 the gill-slits in the throat of the dogfish can be seen exposed.

It is by means of the gills that respiration takes place, the necessary oxygen being obtained from the water flowing through them. A fish inspires by opening its mouth and letting water flow in. It then expires by closing its mouth and passing the water through its gill-slits. Throughout this process, the throat is kept closed, so that the water is not swallowed. As the water flows over the gills it comes into contact with the numerous tiny blood vessels they contain; these give up unwanted carbon dioxide to the water and take fresh oxygen from it into the blood stream. This newly oxygenated blood flows to the various organs of the body and gradually becomes impure as it reacts with the protoplasm; it then passes into a chamber of the heart called the **auricle.** The auricle passes it on to a second chamber called the **ventricle,** and thence it is pumped forward to the gills to be refreshed again.

For nutrition, the dogfish depends on the smaller fish on which it preys. It takes them in by its mouth, which is on the underside and not, as in most fishes, at the end of the head. This food is then passed into the stomach and intestines to be digested. Solid waste matter is excreted through the anus, a

hole situated between the pelvic fins. Tubes conveying liquid waste matter from the kidneys also open into the same hole.

The nasal apertures in the head above the mouth are used, not for breathing, but for smelling. In this way the fish can test the purity of the water into which it swims. It also possesses eyes which have no lids to them, and ears for hearing, although the latter are not visible externally. On the snout of the dogfish are a number of small pores which mark the openings of long tubes fitted with jelly. It is thought that these enable the fish to tell whether it is deep in the water or near the surface, the pressure on the jelly naturally being greater when the fish is deep down. The **lateral line** (Fig. 226) along each side of the body is also believed to be a means by which the fish can detect changes of pressure, and so realise how far below the surface it is swimming.

For reproduction to take place, sperms are produced by special organs in the male dogfish called **testes**, and transferred to the eggs of the female dogfish. The fertilised eggs are then enclosed in an egg-case and laid among sea-weed. Threads attached to the egg-case get entangled in the sea-weed, so that the case is kept in a safe position ; it thus remains undisturbed while the young dogfish develops. Only two eggs are laid at a time, and in this respect the dogfish differs from most other fish, the majority of which lay vast numbers of eggs. As a rule, only a few survive, the rest being eaten by other fish.

The frog is a much more highly developed vertebrate than a fish, although in the early stages of its life it lives in the water, breathes by gills, and in many ways resembles a fish. The mature frog is a mottled brown and green animal living partly on land and partly in fresh water ; it is therefore classed as an amphibian. It is to be found in marshy places and by ponds and streams, but the colour and markings of its skin so camouflage it that it is often difficult to distinguish it from its surroundings. In the winter it **hibernates**, that is, it sinks into a sluggish and sleepy condition, when it scarcely seems to be alive.

For this hibernation or winter-sleep it chooses a sheltered damp spot either beneath a large stone, or in the mud at the bottom of a pond ; in such places it can remain safe and undisturbed. Since it is a cold-blooded animal, its temperature is much lower during the winter months, but in its hibernating state, it manages to survive the winter cold. In February and March it awakes to activity once more and breeding takes place.

Development of the frog. Before considering the mature frog it is interesting to see how it develops from an egg in a jelly-like mass of **spawn** to a small fish-like creature, the **tadpole,** and thence to a tiny frog.

EXPT. 95. **The development of the frog.** (This experiment must be done in February or early March when frog spawn is available). Collect some frog-spawn and place it in a bowl of pond-water together with some water-weeds. Notice that the round black specks are the actual eggs and that they are surrounded by a clear jelly-like substance. Watch them day by day, and observe any changes in their shape. In two or three weeks small black creatures, called tadpoles, will hatch out and cling to the water-weeds in the bowl. Observe them carefully, and notice any changes in their appearance. At six weeks it is advisable to put a little fresh chopped raw meat in the water each day or the tadpoles will eat each other. After seven or eight weeks, legs will be seen to appear ; the tail then disappears and the animal will come to the surface to breathe air. Finally observe the tiny frog that leaves the water and jumps about on the adjacent ground.

Fig. 228 shows the gradual changes that should have been observed during the experiment. The jelly serves as a protection to the eggs before they develop. They gradually become more elongated, and little creatures with large heads and short tails emerge. These attach themselves to the water-weeds by a kind of sucker called a **cement organ.** To begin with, they are blind and have no mouth, their nourishment being obtained from the remains of the egg. After a few days, eyes, ears, gill-slits and mouth appear, and they begin to swim about vigorously by lashing their tails.

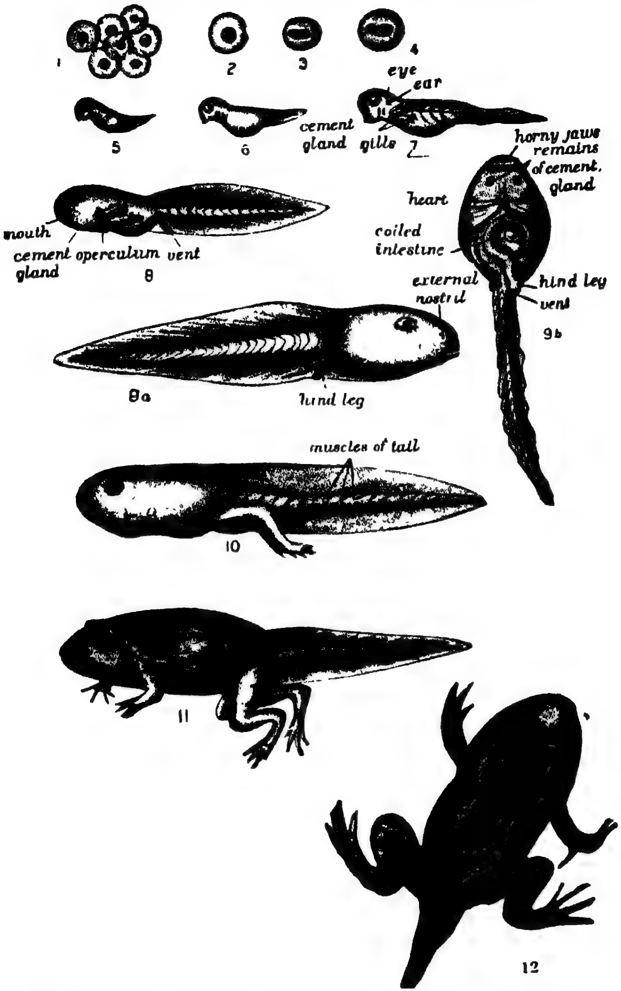


FIG. 228. STAGES IN THE DEVELOPMENT OF THE FROG.

Now that they possess a mouth they nibble at the water-weed. Altogether three pairs of external gills appear as feathery

J.G.S.

tufts on the sides of the head, but these gradually shrivel and internal gills, like those of the dogfish, develop. A fold of skin called the **operculum** then grows over the gill-slits ; this flap is similar to the gill-cover possessed by the more highly developed fish like the herring and haddock. A little later, knobs appear on each side of the tail ; these are the beginning of the hind-legs ; the fore-legs are hidden by the operculum. Gradually the legs increase in size, the fore-legs appear through the operculum, the tail shrinks, and the tadpole now rises to the surface occasionally to breathe air. This shows its lungs are developing and by the time they are fully formed the gill-slits have become closed, and the animal uses its lungs for respiration. When finally the frog takes to the land it moves about by jumping, but it is still quite at home in the water, and can swim by moving its hind-legs and webbed toes.

Skeleton of the frog. The bony framework or **skeleton** of the frog is quite an elaborate structure (Fig. 229). At the back there is a spinal column consisting of nine **vertebrae** and this is continuous with the **skull.** In front there is a breast-bone or **sternum**, but no ribs. The shoulder girdle consists of two shoulder blades or **scapulae** to which the bones of the fore-limbs are attached. The latter consists of an upper arm bone, the **humerus**, connected by a joint to the lower arm bone, the **radio-ulna.** In a human being and many other vertebrates there are two lower arm bones, the radius and the ulna, instead of the single bone possessed by the frog. Wrist or **carpal** bones connect the four fingers and the tiny thumb to

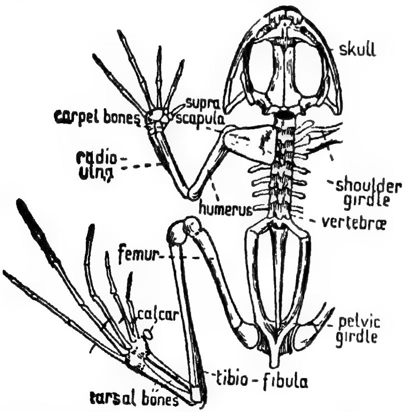


FIG. 229. THE SKELETON OF A FROG.

the radio ulna. In the lower part of the body the **pelvic girdle** supports the bones of the back legs; these each consist of a **femur** and a **tibio-fibula**, another single bone corresponding to the tibia and fibula found in many of the higher vertebrates. Long ankle or **tarsal** bones connect the tibio-fibula to the foot. This consists of five large toe bones and one small extra one, the **calcar**; the web that connects the toes makes the large foot extremely useful for swimming purposes.

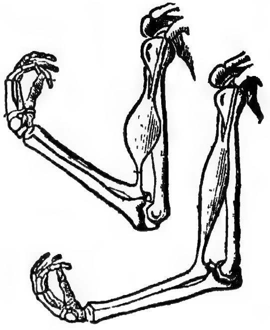


Fig. 230. The use of a Human Biceps Muscle for moving the Forearm.

Most of the movement of the frog, both on land and in water, is due to the action of its hind legs. When it straightens them, an impetus is transferred through the pelvic girdle to the vertebral column forcing the whole body forward. This powerful leg movement is only possible because the leg-bones have strands of **muscle** connecting them. The bones of all vertebrates are moved by muscle in a similar way; Fig. 230 shows how the contraction of the biceps muscle makes it possible for a man to lift his forearm.

Internal structure of the frog. The various internal organs of the frog (Fig. 231) are the brain and spinal cord, the heart, the lungs, the liver, the stomach and intestines, the kidneys and the reproductive organs. These last are called testes in the male animal and ovaries in the female. All vertebrates have similar organs, arranged generally in the same relative positions.

The brain and spinal cord, which are protected by the skull and vertebrae, form the **central nervous system.** From this, nerves go to all parts of the body and control the important functions of respiration, nutrition, excretion and reproduction. In addition, various nerves transmit to the brain messages about the sensations of touch, sight, sound and smell received by the eyes, ears and other organs. They also control any movements

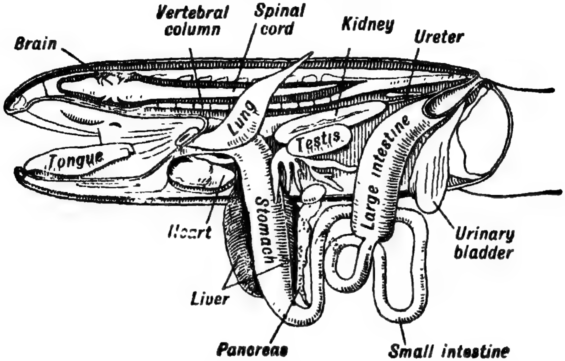


FIG. 231. THE INTERNAL ORGANS OF A MALE FROG.

the frog makes in response to such sensations; for example, he may jump away to shelter if he hears a dangerous sound.

The **heart** of the frog is more complicated than that of the dogfish as it consists of three chambers instead of two; it has left and right auricles and a single ventricle. The impure blood that has circulated through the various organs of the body passes by veins to the right auricle; at the same time freshly oxygenated blood from the lungs passes in the left auricle. Both chambers then discharge into the ventricle, but the tissue therein prevents the blood mixing freely, so that when the ventricle pumps the blood out again the impure blood goes first through the main artery to the respiratory organs to be re-oxygenated; the mediumly oxygenated blood goes next along a second pair of arteries to the trunk and limbs, while the best oxygenated blood goes last through a pair of arteries to the head.

The respiratory organs of the frog consist of its **lungs**, its skin and the roof of its mouth. In all these places, there is a capillary network of blood vessels, so that an exchange can take place between the fresh oxygen of the air and the surplus carbon dioxide in the blood stream. To pass air into its lungs, a frog obtains a large mouthful of air, closes his nostrils and the tube to his stomach, and then swallows hard, so that the air is forced

down into his lungs. During this process some respiration also takes place through the roof of the mouth. The skin must be thoroughly moist for it to serve as an effective respiratory organ, but the frog frequents such damp places that its skin is always slimy. It is by this means that a frog respires when it hibernates at the bottom of a pond during the winter; the dissolved air in the water passes through its skin, and it is thus supplied with all the air it needs in its torpid state.

Fig. 232 Movement of the Tongue of a Frog.

The **stomach** and the small and large **intestines** are concerned with the digestion of food. The frog feeds on worms, insects and snails and it catches these victims by means of its unique tongue. Fig. 232 shows how this organ is attached to the *front* of its mouth pointing backwards; a large portion of it can then be flicked rapidly outwards to seize a fly or other insect. There is a sticky secretion on its surface, so that the prey is caught as if it were on a flypaper, and once in the mouth it is further prevented from escaping by the teeth, and the inward pressure of the frog's eyeballs. Fairly large prey is then swallowed whole, passing down the **gullet** to the stomach. Smaller prey are forced down the throat by the lashing of many small threads, called **cilia**, which are situated on the roof of the mouth. The stomach is continuous with the small intestine and the large one, and while passing through these organs, the food is digested, that is, it is broken and dissolved up into a form in which it can pass into the blood stream. The **liver** and the **pancreas** pass certain digestive juices into the

digestive organs to aid this process. In this way the frog obtains its nutrition. Any undigested food passes out from the large intestine by an opening called the **cloaca**; the watery excretion from the kidneys and the products of the reproductive organs are also expelled through the cloaca.

In February and March a great deal of croaking is often heard as the frogs begin to breed. The female lays large masses of eggs—often a thousand or more—each surrounded by a protective layer of jelly. The male frog then sheds spermatozoa over them, so that they become fertilised, each egg being fertilised by one spermatozoon. Thus masses of frog-spawn are formed, from which tadpoles and new frogs can gradually develop.

The fowl. The fowl is a common domestic bird which is of great value to man because it supplies him with two nourishing protein foods—eggs and its own edible flesh.

The eggs laid by the female fowl (or hen) are very much larger than those of the frog; actually it is only the yolk that is the fertilised egg, the white and shell being extra coverings. Like that of the dogfish, the egg is fertilised within the body of the female, and while passing down the **oviduct** (the tube leading from the ovary) the fertilised egg acquires first a coating of white of egg and then a shell.

Development of the chicken. The development of a chicken from an egg cannot be so easily studied as that of a tadpole, because the opaque shell makes observation difficult, but the structure of a newly laid egg shows an early stage in the development of the chicken.

EXPT. 96. **The structure of a hen's egg.** Take a newly laid raw egg and place horizontally in a glass dish. Then, with a pair of scissors, cut carefully rather less than half the shell away, so that the yolk intact and most of the white remains in the lower portion. Notice that there is an air space at the blunt end between the shell and the **shell-membrane** that surrounds the white. Another thin skin, the **vitelline membrane**, can be seen surrounding the yolk. Look carefully at the white, and notice two thicker parts of it con-

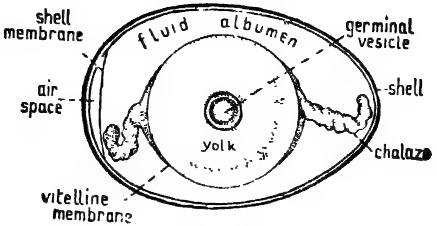


FIG. 233. SECTION THROUGH AN EGG OF A DOMESTIC FOWL.

sisting of twisted strands called **chalazae**; these keep the yolk suspended and enable it to turn; they also act as shock-absorbers (Fig. 233). Now look for a pale spot on the yolk, the **germinal vesicle**; this is the embryo from which the chicken will develop.

Take another unbroken egg and place it in hot water; notice that small bubbles come out of the egg. This shows that gases can pass through the shell.

The natural way for an egg to be hatched is for the brooding hen to sit on it and keep it moist and at a suitable temperature between 99° and 105° F., but often eggs are hatched in incubators, the necessary warmth and moisture being artificially supplied. The yolk is lightest in the neighbourhood of the germinal vesicle, and so by means of the chalazae, the yolk can turn so that the embryo is always at the upper side of the egg nearest the warmth of the mother bird. After three weeks in such warm surroundings the chicken pecks its way out of the egg.

The actual growth of the embryo during these three weeks has been studied by opening eggs each day during the period of incubation. It has been found that the germinal vesicle first becomes pear-shaped, and then a streak appears down the middle of it making the position of the backbone. Gradually brain, nerves and blood-vessels begin to appear. Fig. 234 shows an egg after five day's incubation. The **allantois** is the respiratory organ by which the embryo respires. It was seen in Expt. 96 that gases could penetrate the shell, and the blood-vessels of

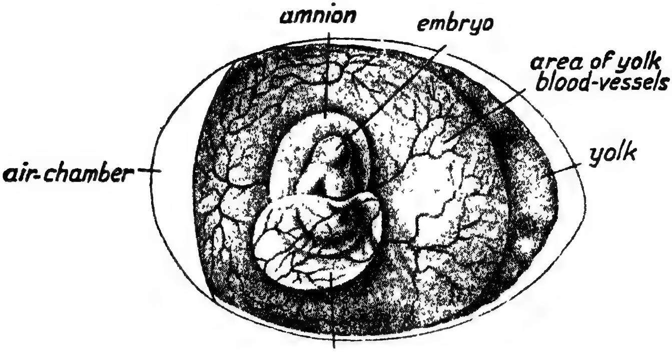


FIG. 234. THE EGG OF THE FOWL AFTER 5 DAYS' INCUBATION. (After Duval)

the allantois absorb oxygen from the air, which diffuses in through the pores of the shell, while waste carbon dioxide diffuses out. The embryo obtains nutrition from the yolk and white which form the rest of the egg ; these are gradually absorbed into its body to supply it with nourishment. When the chicken is fully developed it occupies nearly the whole of the shell, and it then pecks its way out as a fully formed bird.

Skeleton of the fowl. The skeleton of a fowl is familiar to every one, for when the bird is used as a food its flesh has to be carved off the bony framework. Fig. 235 shows the complete skeleton. In many respects it is similar to that of the frog. There are many more vertebrae, and at the lower end they fuse into a bone called the ploughshare bone, which supports the tail feathers. The sternum is large and well formed, and has a definite **keel** ; a strong sternum is necessary for supporting the muscles which enable the bird to fly. The fowl differs from the frog in that it possesses ribs, those attached to the backbone being connected by extensions called **uncinate processes.** At the shoulder there is the " wish-bone " or " merry-thought ", which corresponds to the two collar-bones of a

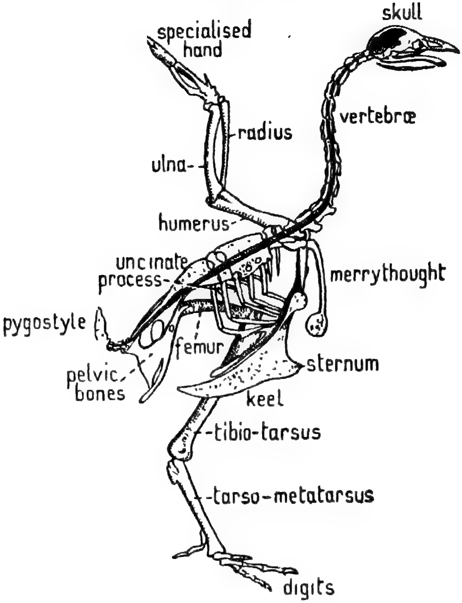


FIG. 235 THE SKELETON OF A FOWL.

human being. The wings have similar bones to the fore-limbs of the frog except that the radius and ulna are separate. The leg bones consist of a femur and tibio-tarsus; to the latter is connected the **tarso-metatarsus,** which is really an ankle bone although it is often regarded as the leg of the fowl.

Internal structure of the fowl. The internal organs of the fowl are similar to those of other vertebrates.

The heart of a fowl is more like that of a mammal and consists of two auricles and two ventricles; there is consequently no mixing of the impure blood with that freshly oxygenated, and so a more complete oxygenation of the blood is secured. This helps to give the bird more energy and vitality than a fish or amphibian.

The process of oxygenation is still further helped by the air sacs in the body of the fowl. These communicate with the lungs and enable it to fill its lungs *completely* with fresh air with each breath it takes.

The first part of the digestive process of the fowl differs from that of the frog and mammals. At the end of the gullet, there is a widened cavity called the **crop,** and in this food is kept for some time until it is softened. It is then passed into a lower cavity, the **proventiculus,** where digestive juices are liberated on to it. From there it goes to the **gizzard,** a thick muscular organ in which food can be ground up. Any girl who can watch a bird being prepared in the kitchen should identify the gizzard ; she will probably find small stones in it, which the fowl has purposely swallowed to assist the grinding up process. The fowl also possesses a liver and a pancreas, which serve the same purposes as those of a frog, such as liberating digestive juices into the intestines, etc.

The development of vertebrates. Mention has already been made of evolution. The study of the different types of vertebrates, as well as an examination of the fossilised remains of animals, has led to the theory that animal life that began in the water gradually invaded the land. Just as the tadpole develops into the frog, so in a similar way some fish may have developed into amphibians. Descendants of certain amphibians then became reptiles, while from the reptiles evolution proceeded in two directions, the bird class developing as one distinct type and ordinary land animals as another.

CHAPTER XXII

THE HUMAN BEING. HYGIENE

Man. The most highly developed form of animal life is found in man himself; gradually he is winning supremacy over all other types of animals and over his material environment. In the last century this has been shown by the way in which he has conquered the air, and established increasingly rapid means of communication and transport.

Nevertheless, man is as yet only in his infancy. It has been estimated that the first amoeba-like forms of life appeared about twelve million years ago, but in the course of evolution eleven million years elapsed before man evolved. Even then he was a primitive animal-like creature, and he can only be said to have been civilised for approximately the last eight thousand years. It seems, then, that if so much can be accomplished in a few thousand years out of the many millions of the past, there is reason to hope that unlimited possibilities exist for his future development, particularly in the realms of the mind and spirit.

The skeleton. The bony framework of the human body (Fig. 236) supports the flesh, protects various important organs, and, with the help of the attached muscles, makes movement possible. Altogether there are over two hundred separate bones connected by joints of various kinds. At the joints, a coating of **cartilage** bathed in fluid over the ends of the bones ensures their smooth working, and the bones themselves are kept in position by fibrous bands called **ligaments.**

The central part of the framework is the vertebral column;

it was seen in Fig. 225 that the upper end of it supports the skull. It consists of thirty-three bones or **vertebrae**, the top twenty-four of which are superimposed but separate, and the lower nine fused into two sections which form the **sacrum** and the **coccyx.** The four fused vertebrae of the coccyx are the relic of a tail, and the five vertebrae above it are fixed into a strong protective belt, the sacrum, which is firmly attached to the hip bones; this complete **pelvis** or **pelvic girdle** of the hip bones and sacrum supports the weight of the upper part of the body. Above the sacrum are five strong **lumbar vertebrae**, and then twelve **dorsal vertebrae**, to which twelve pairs of ribs are attached. Ten of these pairs of ribs are joined by cartilage to the breast bone or **sternum**, but the last two pairs are not connected in this way, and are known as floating ribs. The shoulders are supported by the shoulder blades (or **scapulae**) and collar bones, and this shoulder girdle together with the breast bone and ribs, forms a protective framework for the heart and lungs. The upper arm bone, the **humerus**, is connected by a ball-and-socket joint to the shoulder blade, and by a hinge joint to the two bones of the lower arm, the **ulna** and the **radius.** A ball-and-socket joint (Fig. 237) is one in which the rounded head of a bone fits into a cavity of another bone, thus ensuring freedom of movement in several directions. Such a joint is kept lubricated by a liquid called **sinovial fluid**, which is secreted by a

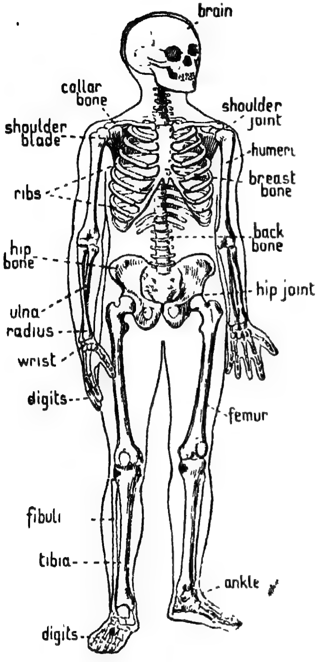


FIG. 236. THE HUMAN SKELETON.

delicate membrane lining it. In a similar way the upper leg bone or **femur** is connected to the hip bone by a ball-and-socket joint, and to the lower leg bones, the **fibula** and **tibia**, by a hinge joint.

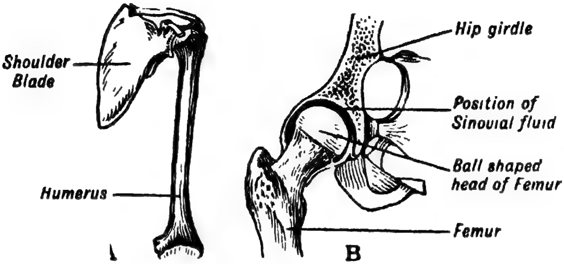


FIG. 237. BALL-AND-SOCKET JOINTS.

EXPT. 97. **The bones of the human body.** Study Fig. 236 or, if possible, the bones of a real skeleton in a museum, and then feel the bones of your own body, identifying them as you do so. Notice the difference in movement of the ball-and-socket joint of the shoulder and the hinge joint of the elbow; the latter only allows movement in one plane.

If the knee of a sheep can be obtained, the working of the joint can be examined, and the presence of cartilage and sinovial fluid can be verified.

Muscles. Fig. 230 illustrates the action of the biceps muscle in lifting the human forearm In a similar way, all the various bones of the body can be made to move by means of the different muscles attached to them. In addition to causing movement of the body, certain muscles do such important work as controlling the action of the heart, the lungs and the digestive organs.

Muscular tissue consists of fibres, bound into bundles by connective tissue and supplied with blood-vessels and nerves. Generally they are thicker at the middle than the ends, and if their work is that of moving a heavy limb, they may be joined to the bone by **tendons** (Fig. 238). When a stimulus is con-

veyed to the muscles by means of the nerves, the fibres can shorten in length and increase in diameter, and this contraction moves the bones as if they were levers ; in Fig. 230 the elbow is the *fulcrum* ; the weight of the forearm, the *load* ; and the pull of the biceps muscle, the *effort*. The point of application of this last force can be determined by lowering the fore-arm and relaxing the muscle ; the tendon attaching the biceps muscle to the radius can then readily be felt.

Actually there are two kinds of muscle, **voluntary** or striped muscles, and **involuntary** or unstriped ones. The former are

Fig. 238. A Muscle, showing a Tendon at Each End.

under the conscious control of the will, and are the ones causing nearly all movements ; they are striped with definite markings, which can be seen with the aid of a microscope. The involuntary muscles work independently of consciousness, and it is these which control the heart and digestion. They are generally arranged in thin sheets, and do not possess the striped markings of the voluntary muscles.

During muscular action, chemical changes take place, and much energy is made available in the form of movement and heat. Everyone is familiar with the way in which any kind of exercise makes the body warm.

The nervous system. It is by means of the nerves that the whole of the body is controlled ; Fig. 239 shows the complicated nervous system extending from the brain and spinal cord all over the body. It is a similar, but more complex, arrangement than that of the frog, and again the brain and spinal cord form the **central nervous system.** In these organs lie the various **nerve centres** which are connected by **nerve cords** to the **nerve endings** in the various parts of the body. Nerve cords consist of bundles of fibres similar to pieces of white cotton ; sometimes

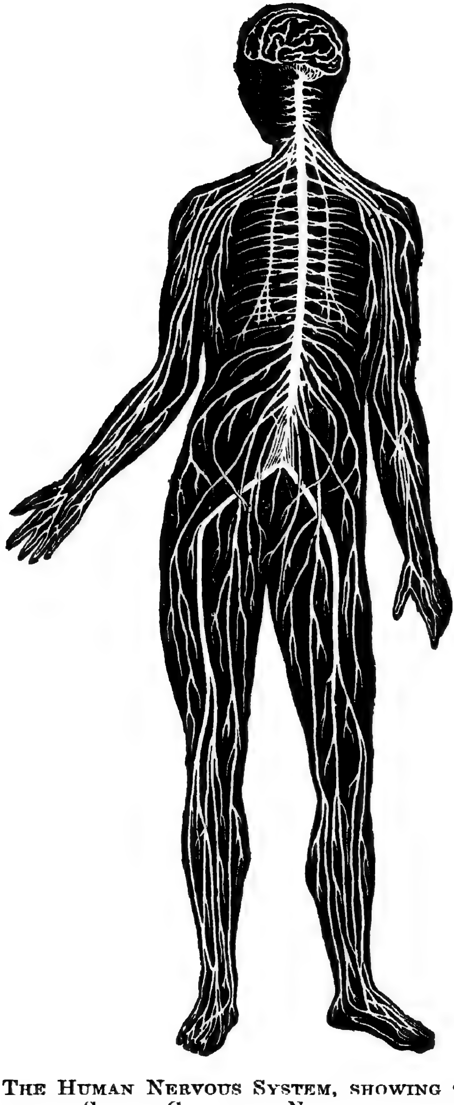


FIG. 239. THE HUMAN NERVOUS SYSTEM, SHOWING THE BRAIN, SPINAL CORD AND NERVES.

a dentist removes a nerve from a sensitive tooth and it can then be seen to be like a little piece of white thread. The nerve endings in a tooth may be stimulated by a patch of decay; they then transmit the sensation through the thread-like nerve cords to the nerve centres in the brain, and the person is conscious of toothache. In a similar way, nerve endings in the finger-tips or anywhere on the surface of the body may transmit to the brain impressions of pain, heat or cold, roughness or smoothness, by means of these **sensory nerves.**

The various senses of smell, taste, sight and sound also depend on the specialised nerve endings that exist in the nose, mouth, eyes and ears. The various messages that travel through the body in this way pass along the nerves at a speed of approximately 472 feet per second. Often the brain, on receiving such a message, sends out a reply in the form of action of the muscles, and the nerves carrying such a message are called **motor nerves** because they cause movement. For example, a girl may be using an electric iron which has become too hot, and she may smell burning, or see a brown mark, or feel the extreme heat. By one or all of these stimuli to the nerve endings in nose, eyes and hand, her brain becomes conscious of what is happening. She accordingly, by an effort of will, passes a message along the motor nerves to her arm to lift the iron from the material which it is burning. Described in this way, it seems as if action is slow, but actually both sets of messages travel along the nerves at 472 feet a second, and from practical experience, everyone knows how quickly it is possible to respond to the sensation received.

Sometimes response is even quicker than that just described, because what is known as a **reflex action** takes place. Many muscular movements are not directly controlled by brain areas and take place automatically. This happens because the sensory nerve impulses are turned back at subordinate nerve centres in the brain or spinal cord, and the motor nerves

respond without the need for conscious judgment by the brain. Sneezing and coughing occur in this way; the irritation of certain nerve endings causes a reflex action not under the conscious control of the brain. In a similar way, such activities as dancing, walking, swimming and playing games are controlled consciously by the brain at first, but with practice they can be performed automatically without the need for thinking about moving a limb in a particular direction, the control having been relegated to a different part of the brain and spinal cord.

The brain and spinal cord. Fig. 225 shows how the brain and spinal cord with their sensitive nerve cells are protected by the bony structure of the skull and vertebral column. The **cerebro-spinal** system consists of three parts, (i) the **cerebrum**, the large upper portion of the brain, (ii) the **cerebellum**, the small lower part at the rear, and (iii) the **medulla oblongata** continuing downwards to the spinal cord. The cerebrum consists of large

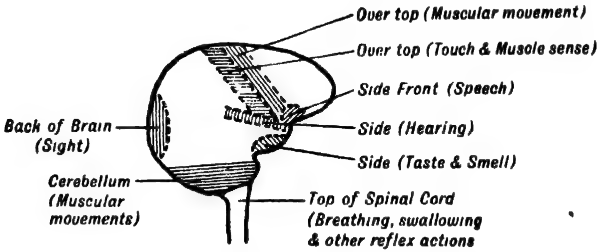


FIG. 240. DIAGRAMS TO SHOW SOME OF THE REGIONS AND AREAS OF THE HUMAN BRAIN.

masses of coiled and twisted nervous matter divided into right and left cerebral hemispheres, which are separate at the top, but joined lower down in the brain. Outside them is a tiny layer of **grey matter**, with which is associated many activities of the mind and intelligence. Different areas of the cerebrum control the various senses of smell, taste, hearing and sight (Fig. 240) as well as muscular movement. A curious fact is that the nerves cross over, so that the *left* cerebral hemisphere con-

trols the *right* side of the body and vice versa ; thus an injury to the left side of the brain may result in paralysis of the right side of the body.

The smaller lower part of the brain, the cerebellum, is concerned with the co-ordination of the ordinary nervous and muscular movements of the body, as, for example, walking and eating. A person may be unconscious as the result of an injury to the cerebrum, but still be able to take food because the cerebellum is uninjured.

The medulla oblongata controls certain automatic movements of the body like breathing and swallowing and various reflex actions.

In addition to the cerebro-spinal system, which governs muscles under the control of the will, there is the **sympathetic nervous system** which is concerned with regulating involuntary muscles. It consists of groups of nerves closely connected with the spinal cord, and these automatically regulate the blood-vessels and such bodily functions as digestion and excretion.

All parts of the brain are plentifully supplied with blood-vessels. In fact, all tissues and cells of the body depend on the blood stream for supplying the nutrition and oxygen they need.

The heart. Blood is distributed throughout the body by means of the **heart**, the **arteries**, and the **veins**. The heart acts as a pump to force the blood through the various blood-vessels. Arteries carry blood *away* from the heart, while veins carry it back *towards* the heart. In addition there are tiny blood-vessels called capillaries, through whose walls gases and fluids can diffuse.

All mammals have similar four-chambered hearts consisting of two auricles and two ventricles. The working of the human heart can be more readily understood if that of a sheep is first examined.

EXPT. 98. **Examination of a sheep's heart.** Obtain a sheep's heart ; notice its shape and the four tubes that emerge from the blunt end. Two of these are arteries and two are veins. To discover

which is which, attach a piece of pressure tubing to a tap and to each of the tubes in turn, turning the water on gently after making the connection. The tubes which let water into the heart must be veins Notice that the walls of the veins are thinner than those of the arteries. Fill the heart with water and squeeze the lower part of it. At each contraction water will squirt out of the two arteries. This shows how blood is pumped out, when the muscles keep the heart beating in the normal way.

Now cut the heart across, and try to identify the two auricles and the two ventricles. The latter are in the lower pointed end, and can be seen to have much thicker walls than the other chambers.

The human heart also consists of four chambers, a right auricle and right ventricle, and a left auricle and left ventricle. Valves control the flow of blood in and out of these various chambers, but there is no communication between the right and left sides of the heart. Fig. 241 shows a sectional diagram of

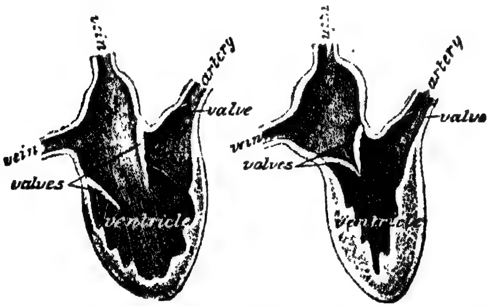


Fig. 241. Section through One Side of the Human Heart.

one side. In the first figure, blood is flowing from the veins into the auricle, and thence through a valve into the ventricle. In the second figure, the ventricle is contracting and forcing the blood out through the artery, the valve to the auricle now being closed ; the diagram shows how the walls of the ventricle are much thicker than those of the auricle, a stronger compartment being needed for such a forcing action. On both sides of the heart blood flows in, and is pumped out, in a similar fashion.

Circulation of the blood. Fig. 242 illustrates the way in which the blood circulates round the body; the arteries are coloured red, and the veins blue. Freshly oxygenated blood from the lungs, bright scarlet in colour, flows through the **pulmonary vein** into the left auricle of the heart. It then passes into the left ventricle, and is pumped out through a large artery called the **aorta.** From the aorta it branches off to various arteries, which supply the different organs of the body with blood. Thus one branch goes to the capillary network in the intestines, another to that in the liver, and yet others to the capillary networks in the head and limbs. Through the walls of all these capillaries, nutriment and oxygen from the blood is passed to the various cells of the body, waste products and carbon dioxide being received back in exchange. In this way, the pure arterial blood is changed into impure venous blood, and leaves the various organs by veins which are marked blue in the diagram. The different veins join up to form the **vena cava,** which brings the impure blood back into the right auricle of the heart. Thence it flows into the right ventricles, and is pumped out through the pulmonary artery to the lungs to be freshly aerated again.

An additional function of the blood flowing through the stomach and intestines is that of carrying the products of digestion, which pass into it in that region, through the **portal vein** to the liver. The liver then extracts some of the nourishment in the form of carbohydrates, and stores it away in the form of glycogen for future use. The impure blood then leaves the liver by the **hepatic vein,** and passes on to join the vena cava.

In the case of severe injuries where blood-vessels are severed, arterial blood can always be recognised by its bright red colour, and by the spurting way in which it flows, each spurt corresponding to a beat of the heart. Venous blood, on the other hand, is darker in colour and flows more evenly.

The beating of the heart corresponds to its pumping action,

and in normal adults this contraction takes place from seventy to eighty times a minute. At each beat, fresh blood is forced along the arteries, and the pulse that can be felt in the artery of the wrist is due to these successive impulses of blood through it.

The corpuscles of the blood. When examined under a microscope, blood can be seen to contain enormous numbers of tiny particles called corpuscles (Fig. 243). The majority of them are red, but a few are white, the proportion being 500 to 1 for a person in normal health. The two kinds of corpuscles have different work to do.

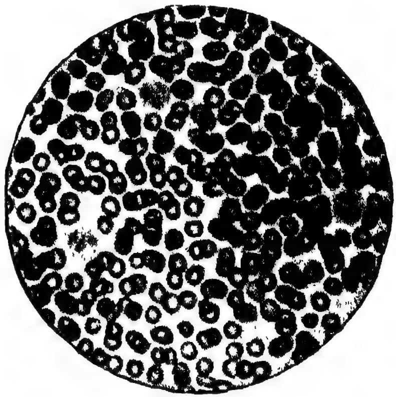


FIG. 243. BLOOD SEEN UNDER THE MICROSCOPE.
(From a photograph.)

It was seen in Chapter XVII that the red ones contain a red pigment called haemoglobin, which has the power of combining with the oxygen it obtains in the lungs and carrying it through the body to give it up to the various cells and tissues; it then receives the unwanted carbon dioxide and carries it back to the lungs. The more oxygen the haemoglobin contains, the brighter its colour; hence the difference in colour of arterial and venous blood.

The white corpuscles are very similar to amoeba; their work consists in fighting any bacteria that get into the blood stream by engulfing and destroying them. If the white corpuscles are numerous and active, a person may successfully resist the bacteria of a disease, but if the white corpuscles do not maintain the mastery, illness may result. The pus of an abscess contains dead white corpuscles which have been overcome by invading microbes.

Lymph. The lymphatic system shown in Fig. 242 consists of an arrangement of vessels and capillaries containing **lymph,** a colourless fluid resembling blood, but containing no corpuscles. This fluid carries out the very important work of taking nutriment from the digestive products in the blood stream and conveying it to cells and tissues in all parts of the body; it then returns to the blood stream with waste products from the tissues; these impurities then pass by the lymphatic ducts into the vena cava. Thus the lymph plays an important part in transferring nutriment from the blood to the cells of the body.

The lungs. The importance of respiration for supplying all living organisms with energy has already been described on page 253. In human beings, the **lungs** supply the blood stream with the oxygen it needs for carrying on this important process. The two lungs are situated in the chest cavity, one on each side of the heart, the ribs serving as a protection to them (Fig. 244). Air entering by the mouth and nose passes through the windpipe or **trachea,** to two main tubes called **bronchi,** and these each pass to a lung. Each bronchus on entering the lung divides up into numerous branching smaller tubes which end in tiny air sacs. A network of fine capillary blood-vessels lines the air sacs, and oxygen can diffuse through the thin membrane separating them from the blood stream, while carbon dioxide and water vapour can pass in the opposite direction back into the lungs. Expt. 25 showed that the air breathed out contained a larger proportion of carbon dioxide than that breathed in. When inspiration takes place blood in the capillaries of the lungs changes from dark venous blood to bright arterial blood, because it loses carbon dioxide, and gains fresh oxygen.

The movement of the chest that is called breathing normally takes place about fifteen times a minute. The muscles causing the movement are those which raise the ribs, and a strong muscle, the **diaphragm,** which separates the chest cavity from the abdominal one and supports the bases of the two lungs.

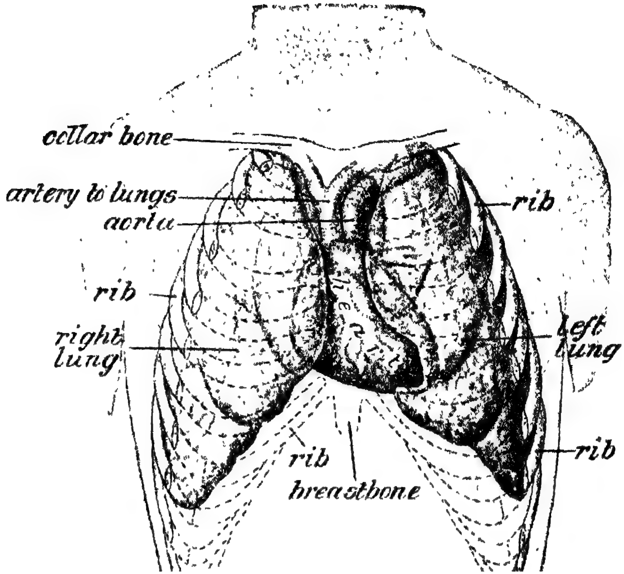


FIG. 244. DIAGRAM TO SHOW THE RELATIVE POSITIONS OF THE HEART, LUNGS AND RIBS.

When the diaphragm is depressed and the rib muscles are in action, the chest cavity is deepened and widened ; the lungs therefore expand, and air is drawn in. When the muscles relax, the chest and diaphragm fall back into their natural position and air is expired. This process goes on rhythmically and regularly so that the lungs, and, consequently the blood stream, are kept supplied with oxygen.

Nutrition. In addition to respiration, nutrition is essential for the supplying of living organisms with energy. Human beings and other animals obtain nourishment by eating food, which is converted by the process of **digestion** into materials that can be absorbed into the blood stream. The various

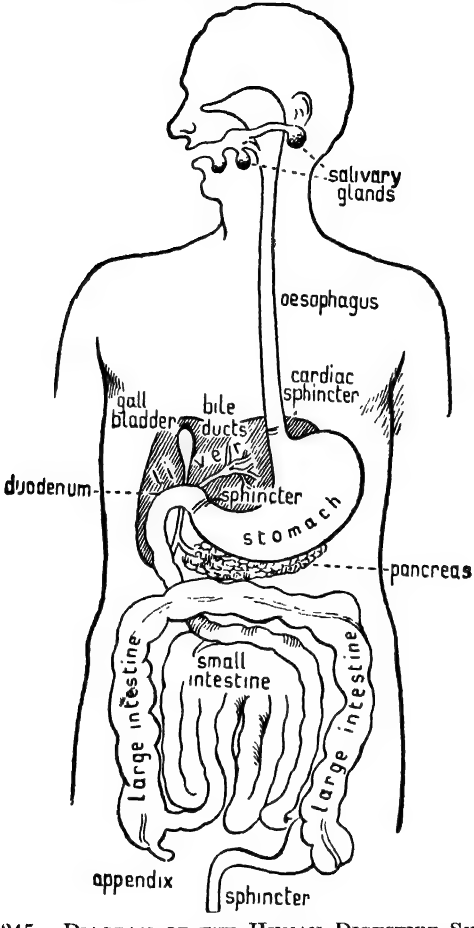


FIG. 245. DIAGRAM OF THE HUMAN DIGESTIVE SYSTEM

organs of digestion are the **mouth,** the **stomach** and the **small** and **large intestines** (Fig. 245). The various kinds of foodstuffs that are essential for human nutrition were described on page 251 ; they consist of proteins, carbohydrates, fat and oils, mineral

salts and vitamins. A study of the various parts of the human digestive system shows how these different substances are absorbed into the blood stream to supply the body with nutrition.

The human digestive system. Fig. 245 shows the whole of the **alimentary canal,** that is, the tube through which food passes in the human body. At its upper end is the mouth, and this is connected by means of the **oesophagus** to the stomach ; the entry of food to the stomach is regulated by a muscular valve or **sphincter muscle.** At the other end of the stomach another sphincter controls the food passing through the **duodenum** to the small intestine. This consists of a coiled tube some twenty feet in length, along which the food is squeezed by the muscular contractions and movements of its walls (Fig. 246). During its passage through the mouth, stomach and the small intestines, most of the digestive process is completed, but undigested food and water remain, and these are passed on to the large intestine. There water is absorbed and the undigested food is expelled from the **rectum**, through the anus.

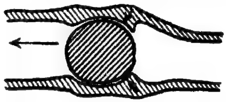


FIG. 246. DIAGRAM TO SHOW HOW A PORTION OF PARTLY DIGESTED FOOD IS SQUEEZED ALONG THE INTERNAL TRACK.

Digestion. The digestive process begins in the mouth. Food is masticated by the teeth and moistened by the **saliva,** an alkaline liquid secreted by the glands under the tongue and on both sides of the jaw. In man, the saliva contains a ferment **ptyalin,** which converts insoluble starch food, like potatoes and bread, into sugar, a soluble substance which can be more readily absorbed. Thus digestion begins in the mouth with the changes produced in certain carbohydrates ; proteins and fats pass on to the stomach and small intestine before undergoing any digestive action.

In the stomach more digestive glands secrete the **gastric juice,** an acid liquid containing two ferments, **renin** and **pepsin.** Pepsin acts on protein foods like meat and eggs, and converts them into

soluble substance called **peptones.** Renin curdles milk, etc. The muscles of the stomach produce a churning motion on the food within it, and some of the peptones and sugars pass into the blood stream by the capillaries lining the stomach, while the rest of the food passes on in the form of a churned-up soupy substance called **chyme.**

The duodenum is the upper part of the small intestine, and as the chyme passes through it, it receives more important digestive juices, **bile** from the liver and **pancreatic juice** from the pancreas. The bile acts on fats and emulsifies them, while the pancreatic juice contains ferments which change the rest of the starchy substances into sugar, decompose and emulsify fats, and convert proteins into peptones. In addition, an **intestinal juice** from the walls of the intestine helps to complete the work of digestion. By the time the chyme is half-way through the coils of the small intestine, it has been changed into a soluble form in which it can pass through the lining of the intestine to the capillary blood-vessels. It is therefore in the last half of the small intestine that most of the absorption of nutriment into the blood stream takes place; only a relatively small amount of absorption occurs in the stomach.

In the large intestine, any nourishment remaining is absorbed together with a large quantity of water. The undigested substances are then discharged at the **anus** in the form of **faeces.**

Excretion. The processes of respiration and nutrition, which are so essential to the life of man, lead to the formation of waste products, which must be excreted from the system, if health is to be maintained. These excretions are in the form of solids, liquids and gases. The removal of waste solid matter from the rectum has been described in the previous paragraph; the removal of waste liquids is achieved by the skin and kidneys, and that of gaseous products by the expulsion of water vapour and carbon dioxide from the lungs during expiration.

The kidneys. The two kidneys lie one on each side of the spinal column in the upper part of the abdominal cavity. They

act as filters to all the blood passing round the body and remove from it various impurities, the chief of which is the nitrogenous waste matter, urea ; this dissolved in water constitutes the urine. The structure of the kidneys can best be understood by studying those of a sheep, although human kidneys are a good deal larger and are about 4½ inches in length.

EXPT. 99. **Examination of a sheep's kidneys.** Notice the shape of the kidneys and the protective layer of fat that surrounds them. Cut one in two longitudinally, and observe the collecting tubes arranged round the inner part of the kidney and which join up to a main collecting tube. Notice that the outer part of the kidney is redder, owing to the presence of more blood vessels.

In addition to the tubes visible in the sheep's kidneys numbers of minute ones are also present, and these join up to form the larger visible tubes. In the human kidney (Fig. 247) there are eight to twelve of these collecting tubes, which join up to the main exit tube, the **ureter.** The waste fluid that collects in the tubes and passages to the ureter has been filtered from the blood stream by the capillaries at the ends of the tubes. It then passes as urine from the two kidneys down the two ureters to the **bladder.** There is collects until it is expelled from the body.

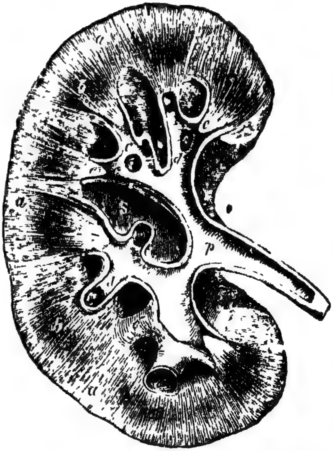


FIG. 247. A HUMAN KIDNEY.

The skin. The kidneys and the skin work together in excreting waste liquid from the body. When the weather is cold there is little perspiration, and the kidneys excrete more urine ; when it is hot the skin gives off more moisture, and the kidneys excrete less urine.

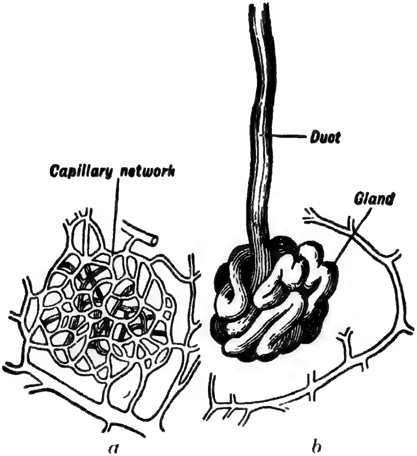


FIG. 248. A SWEAT GLAND.

The **sweat glands** of the skin consist of tiny coiled tubes connected to the surface by short straight tubes (Fig. 248, *b*). There is a capillary network of blood-vessels round each gland (Fig. 248, *a*), and waste products from the blood stream, in the form of water and salt, pass into the coiled tube and so reach the surface of the skin. There the moisture either evaporates or appears as beads of perspiration.

State hygiene. The importance of **hygiene**, that is, of keeping the body in good health, is being increasingly recognized in the world to-day, and governments, as well as individuals, are interested in trying to ensure a high standard of physical fitness amongst the population. Thus the state has concerned itself with certain measures for promoting public health by forming a Ministry of Health which acts through the Medical Officer of Health of each borough. This M.O.H. has, under his control, clinics for the care of mothers and children and for the supervision of the health of school children. He is also responsible for the purity of the water-supply and of the milk sold in his

borough. Housing conditions are another of his concerns; he advises the local government on such matters as the disposal of sewage, the provision of public wash-houses, and plans for slum-clearance. He also has powers to prevent the pollution of the air by fumes, and of rivers by chemicals, resulting from manufacturing processes.

When infectious diseases occur, certain of them, as, for example, scarlet fever and diphtheria, must be notified to the local Medical Officer of Health, so that he may take measures to prevent their spreading. He may order that members of the family of the patient should not attend school, but be kept in quarantine for varying periods, and the patient may be removed to an isolation hospital. In the case of tuberculosis, a sufferer may be sent to a sanitorium if home conditions demand it. Sometimes infectious diseases can be checked by particular preventative methods; for instance, smallpox, which was once very widespread in this country, has been almost eliminated by vaccination.

Personal hygiene. It was seen on page 285 that many diseases are due to the invasion of the body by harmful disease-producing bacteria, and the best way of combating such infection is by *preventative* methods; the old maxim that "Prevention is better than cure" is a sound one. The surest method of preventing bacterial disease is by maintaining the body in such a state of good health that bacteria are unable to obtain a hold on the human system. This is best achieved by means of attention to: (1) personal cleanliness, (2) keeping the body fit by outdoor exercise, fresh air and sunshine, (3) using antiseptics when infection may occur, as, for example, by applying iodine to a cut or abrasion. In addition to fresh air and sunshine, the human body also needs to be supplied with suitable clothing and suitable food; the question of diet and vitamins has already been discussed on page 252.

Conclusion. Both personal hygiene and State hygiene aim at making the human being as healthy and strong as

possible during his life on this earth. All the other scientific knowledge outlined in this book should help him to understand, and have mastery over, his environment, so that he can use all the resources of science to improve his communal life, and make himself a happy, healthy and useful citizen of the world.

EXAMINATION QUESTIONS

The questions subjoined have been selected, by kind permission of the authorities concerned, from recent papers set by :

1. Oxford and Cambridge School Certificate (O.&C.S.C.) ;
2. London General Schools (L.G.S.) ;
3. Central Welsh Board School Certificate (C.W.B.S.C.) ;
4. Oxford School Certificate (O.S.C.) ;
5. Cambridge School Certificate (C.S.C.).

FUNDAMENTAL PRINCIPLES

1. How do you think the solar system may have been formed ? (O.&C.S.C.)

2. Define the *centre of gravity* of a body. The centre of gravity of a boxwood metre scale, which has some holes bored in it, is at the 49 cm. mark. Being supplied with a 50-gram weight, and using the scale as a lever, describe how you can determine its weight.

Give an example in illustration, if this weight is found to be 100 grams. • (L.G.S.)

3. State the principle of the action of a simple pulley. Explain, with the aid of diagrams, how pulleys can be used to open and close curtains. (L.G.S).

4. When is a force said to do work ? How is this work measured ?

A man, whose weight is 160 lb., walks 100 yards up a hill, which rises 1 foot in every 12 feet of its length. What amount of work has he done against gravity ?

If he walks up the hill at the rate of 3 miles an hour, at what average horse-power is he working against gravity ? (C.W.B.S.C.)

5. The sides of a triangular sheet of brass are 6, 8 and 10 cms. respectively and it is of uniform thickness (1 millimetre). If the density of the metal is 8·5 grams per c.c., show that its mass is 20·4 grams. (L.G.S.)

6. State the principle of Archimedes, and describe how you would verify it by experiment.

A hollow stopper, made of glass of sp. gr. 2·5, weighs 40 grams in air, but appears to weigh only 17 grams when totally immersed in water. What is the volume occupied by the cavity in the stopper ? (C.W.B.S.C.)

7. How would you make a simple instrument to measure the pressure of the air ? In what respects would your instrument differ from the accurate one in the laboratory ? Explain how you would take an accurate reading of the pressure of the air. (O.S.C.)

HEAT

8. What apparatus would you use, and how would you proceed, to ascertain whether or not the fixed points on a Fahrenheit mercurial thermometer were correctly marked ? (O.S.C.)

9. Describe the construction of a clinical thermometer, and explain how it is set.

The normal body temperature is 98·4° F. What would this temperature be on the centigrade scale ? (C.W.B.S.C.)

10. What is meant by the "specific heat" of a substance ? How would you determine the specific heat of lead ? Show how you would calculate the result from your observations. (O.S.C.)

11. *Either* What is the British Thermal Unit ? A therm = 100,000 B.TH.U. What is the cost of heating the water for a 50 gallon bath from 40° F. to 80° F. with gas at 10*d*. per therm ? 1 gallon of water = 10 lb.

Or Define the thermal capacity of a body. A lump of metal weighing 500 gm. is heated to 100° C. and then dropped into 800 gm. of water at 15° C. The temperature rises to 20° C. Find the thermal capacity of the lump of metal and the specific heat of the metal. (C.S.C.)

12. Explain the following :

(*a*) An open fire is a good aid to the ventilation of a room.

(*b*) A glass stopper which has become fixed in the neck of a bottle can often be released by warming the neck gently.

(*c*) Steam causes more severe burns than water at the same temperature.

(*d*) The dentist warms his small mirror before putting it in the patient's mouth. (C.W.B.S.C.)

13. Name the instruments suitable for measuring the following and with the aid of sketches describe *two* of them, explaining how they are used :

(*a*) The lowest night temperature of a greenhouse.

(*b*) the weight of a lump of lead,

(*c*) the pressure of the atmosphere,

(*d*) the rainfall. (C.S.C.)

14. Glaciers are sometimes described as " rivers of ice." Discuss this description.

What evidence is there that glaciers once travelled over districts where they are not now found ? (C.W.B.S.C.)

15. What is meant by the " relative humidity " of the air ? How would you find the relative humidity on a given day ? (O.S.C.)

16. Explain the reasons for the following :

(*a*) Winds blow outwards from the centre of a region under the influence of an anticyclone and inwards to the centre of a cyclonic area.

(*b*) At a seaside place the climate tends to be more equable than inland. (O.S.C.)

17. Describe a system of heating a building by hot-water. Include a sketch of the essential parts showing clearly the course taken by the water.

Explain carefully the various methods of heat transmission involved in the passage of heat from the boiler fire to a person in one of the rooms. (C.S.C.)

18. What changes in the air of a room cause it to become " stuffy " ? In what ways are they harmful to health ? (C.S.C.)

19. Describe the construction of a modern gas fire, showing how the products of combustion are removed and any arrangement intended to assist ventilation. By what process does heat from such a stove reach the occupants of a room ? Name any dangerous combustion product which may be formed, and state the conditions which may cause its formation. (C.S.C.)

20. Explain as fully and clearly as you can any *two* of the following:

(*a*) the bursting of water-pipes in frosty weather ;

(*b*) the part played by a fire place and chimney in the ventilation of a room ;

(*c*) the fact that in fine warm weather black clothes are " hotter " than white ones of similar weight and thickness. (O.S.C.)

21. Explain the following :

(*a*) Wet clothes feel cold to the body.

(*b*) A pendulum clock generally " loses " in hot weather.

(*c*) White clothes are usually worn in the tropics.

(*d*) A lead bullet, travelling at a high speed, will often melt when it strikes an iron target. (C.W.B.S.C.)

SOUND AND LIGHT

22. What reasons are there for thinking that sound consists of a wave motion propagated through the air ? (O.&C.S.C.)

23. Explain the production of an *echo*.

How can this principle be used, during a fog, to estimate the distance of a ship from the shore if the latter is bounded by high cliffs ? (L.G.S.)

24. Explain what is meant by the refraction of light.

A beam of sunlight falls obliquely on a thick plate of glass and then upon the face of a thin wedge-shaped prism. Draw a rough diagram illustrating the path of the sunbeam successively through the plate and prism. (O &C.S.C.)

25. Give an account of an experiment which you have performed or witnessed relating to *refraction* of light.

State clearly what you learnt from the experiment. (L.G.S.)

26. " The eye is like a camera." To what extent is this analogy true, and in what respects does the eye differ in principle from a camera ? (O.&C.S.C.)

27. Explain the following observations :

(*a*) It is much more painful to drink a hot liquid out of an aluminium cup than out of a porcelain cup.

(*b*) Sound usually travels farther over a lake than over the open countryside.

(*c*) Short-sighted people are able to see things clearly at a much smaller distance from the eye than those with normal vision. (O.&C.S.C.)

28. State in each of the following cases whether the image is *real* or *virtual, magnified* or *diminished, erect* or *inverted* :

(*a*) one's hand seen in a plane mirror,

(*b*) an insect viewed through a magnifying glass,

(*c*) a penny at the bottom of a bowl of water,

(*d*) a house as seen on the ground glass screen of a camera.

Draw diagrams showing how the images are seen in *two* of the cases. (C.S.C.)

29. Describe *two* experiments illustrating the nature of white light. Explain the difference in appearance between (*a*) white bodies, (*b*) black bodies, (*c*) blue bodies, (*d*) blue bodies illuminated by yellow light. (O.&C.S.C.)

30. Explain *three* of the following :

(*a*) A straight stick dipping into water at an angle of 30° to the vertical appears bent. Show in a diagram how it seems to be bent.

(*b*) When the image of a candle flame in a thick plate glass mirror is observed it is possible to see a number of fainter images, one in front and the others behind the main image.

(*c*) A flower which appears bluish purple in daylight appears red in an artificial light which is deficient in blue.

(*d*) When a cloud passes in front of the sun one feels colder immediately although the temperature of the air is unchanged.

(*e*) A sound travels farther along the ground with a following wind than against a head wind.

(*f*) Curtains and other soft materials are often hung in a hall to improve its acoustics.

(*g*) Bar magnets are stored in pairs with two soft iron keepers.

(*h*) The iron retort stands in a laboratory are often found to be magnetised. Which pole is found at the top of the stand ?

(*i*) A 40-watt gas-filled lamp gives more light than a 40-watt metal-filament (vacuum) lamp and its filament is smaller. (C.S.C.)

MAGNETISM AND ELECTRICITY

31. Explain the difference between the magnetic properties of steel and those of soft iron. Which substance would be the more suitable in the construction of (*a*) a compass needle, (*b*) the armature of a dynamo, (*c*) an electromagnetic hoist or crane ? Give reasons for your answers. (O.&C.S.C.)

32. Describe *two* simple experiments, which you have seen or performed, to illustrate the production of induced currents.

Explain any *one* application of current induction in everyday life. (C.W.B.S.C.)

33. Describe and explain the principle of *two* of the following :

(*a*) A maximum and minimum thermometer *or* a Thermos flask.

(*b*) A common pump.

(*c*) A convex mirror used as a driving mirror on a car.

(*d*) An electric bell. (C.S.C.)

34. Describe hygienic methods of removing dust and dirt from carpets and upholstery. Explain the scientific principle underlying the construction of the apparatus used. (L.G.S.)

35. Describe *two* experiments illustrating electromagnetic induction. Explain how it is applied in a dynamo to convert mechanical energy into electrical energy. (O.&C.S.C.)

36. Describe the construction, and explain the action, of (*a*) an electric bell, (*b*) a telephone receiver. (C.W.B.S.C.)

37. Answer *three* of the following :

(*a*) Milk can be kept cool in hot weather by placing a bottle of it under a cover made of porous pot which has been soaked in water. Explain the principle involved.

(*b*) A room is lighted by a 700 watt lamp, the mains being at 200 volts. Switching on a 3 kilowatt radiator dims the lamp. Why is this ? How could the dimming be avoided ?

(*c*) Three flowers are placed in a stand ; you are told that their colours are white, yellow, red. You are asked to identify them by inspection, first in yellow light and then in red light ; what changes in appearance will assist you ? (C.S.C.)

38. What is meant by electrolysis ? Describe the electrolysis of a solution of copper sulphate with copper electrodes. Mention *two* practical applications of electrolysis. (O.&C.S.C.)

39. Give an account of the process of electro-plating. (O.&C.S.C.)

40. State and explain what is seen to happen when an electric current is passed through :

(*a*) A very thin wire,

(*b*) A solution of copper sulphate between platinum plates,

(*c*) A long wire held near to a compass needle.

Describe any application in everyday life of *one* of these three results. (C.W.B.S.C.)

41. Answer *either* (*a*) *or* (*b*) :

(*a*) " Repulsion is the only true test of electrification." Explain what is meant by this statement and describe a simple experiment in illustration of it.

(*b*) Describe carefully how you could magnetise a steel knitting needle AB so that the end A may become N. seeking.

State what new properties the needle possesses after it has been magnetised. (L.G.S.)

CHEMISTRY

42. Describe experiments, which you either have seen or have carried out, to ascertain the conditions under which iron rusts. How would you change the iron rust back into iron ? Sketch the apparatus which you would use. (C.W.B.S.C.)

43. Give the approximate composition of ordinary air. Explain the differences you would expect to find between the normal composition of air and that of the air of (*a*) a stuffy room, (*b*) a coal mine. (O.&C.S.C.)

44. Name *three* important constituents of the atmosphere. Describe the part played by any *one* of them in the lives of plants and animals. (O.S.C.)

45. How is carbon dioxide prepared ? Mention any uses for which this substance is produced commercially on the large scale. Indicate briefly its importance in relation to vegetable life. (O.S.C.)

46. How would you show that :

(*a*) water is a compound of hydrogen and oxygen ;

(*b*) when a candle burns in air, water is produced ;

(*c*) air contains a gas or gases other than oxygen ?

(C.W.B.S.C.)

47. Describe an experiment by which the composition of water *by weight* can be determined.

Point out the precautions necessary in carrying out this experiment. (L.G.S.)

48. Explain the effect of "hard" water on soap. Describe how natural waters become hard and explain how they may be softened. (O.S.C.)

49. Give an account of *one* household method of softening each of the following, stating clearly the chemical reactions which take place:

(*a*) temporarily hard water ;

(*b*) permanently hard water.

Explain why hard water to which soap has been added becomes turbid. (C.S.C.)

50. What is meant by "hard" and "soft" water ? How would you determine which of two samples was the harder ? What kind of water is likely to damage a boiler, and why ? (O.S.C.)

51. Describe experiments which you yourself would perform to show *two* of the following. Give one experiment with a diagram in each case.

(*a*) When dry hydrogen burns in air water is formed.

(*b*) When hydrogen chloride is oxidised chlorine is formed.

(*c*) The production of nitrogen from the air.

(*d*) That hydrogen is a reducing agent. (C.S.C.)

52. Explain the use of washing soda in each of the following cases : (*a*) in the laundry, (*b*) in the kitchen for cleaning purposes, (*c*) in a chemical fire-extinguisher. (L.G.S.)

53. State a distinguishing *chemical* property of a metal and a non-metal respectively. Illustrate your answer by reference to *iron* and *sulphur*.

Describe two chemical compounds which contain only these two elements.

Do you consider that graphite is a metal or a non-metal ? Give your reasons. (L.G.S.)

54. Answer *either* (*a*) *or* (*b*) :

(*a*) By what physical and chemical tests can you identify the metal *copper* ? Name two uses of copper in everyday life and describe one of its chemical compounds.

(*b*) What is the chemical nature of the substance commonly known as black lead ? Give experimental evidence in support of your answer. State three important uses of this substance. (L.G.S.)

55. Describe the experiments, *one* in each case, which you would make to distinguish between :

(*a*) nitrogen and carbon dioxide ;

(*b*) washing soda and baking soda, both being in a powdered form ;

(*c*) quicklime and chalk ;

(*d*) powdered coal and powdered coke. (C.W.B.S.C.)

56. *Either*, (*a*) Write an account of the importance, in nature, of the solvent action of water.

Or, (*b*) Discuss the relative advantages, as fuels, of coal and coal-gas. (O.S.C.)

57. Explain what happens (*a*) when ordinary coal is burnt in an open grate, (*b*) when it is burnt with a restricted supply of air, and (*c*) when it is heated in a closed retort. In each case what differences would be observed between anthracite and soft coal ? (O.&C.S.C.)

58. What are the chemical reactions that occur in (*a*) a blast furnace, and (*b*) a lime kiln ? Give equations. (O.&C.S.C.)

59. Write down the names and formulae of two substances in each of the following classes : *Acids, bases* and *salts*.

Describe in detail how you could prepare a salt from an acid and a base which you have selected. (L.G.S.)

60. What are *salts* ? Describe *three* ways of preparing salts, giving an example in each case. (O.S.C.)

61. What are the reasons for considering that (*a*) sulphur is a non-metal, (*b*) lead is a metal, (*c*) carbon dioxide is a compound, (*d*) sulphuric acid is an acid, (*e*) caustic soda is an alkali ? (C.S.C.)

62. How would you prepare chlorine in the laboratory ? Give the equation for the reaction. Describe the physical properties of chlorine, and explain any *one* of its common uses. (O.&C.S.C.)

63. Explain the importance of nitrogen in relation to life, and give a short account of the " nitrogen cycle " in nature. (O.&C.S.C.)

64. For what reason does a farmer work on a " rotation " of crops ? Give an example of a rotation to include a bare fallow, and explain its use. (O.S.C.)

65. Explain the use of lime (*a*) in building, (*b*) as a water-softener, and (*c*) as an application to the soil. (O.&C.S.C.)

BIOLOGY

66. Enumerate the various characteristics of living organisms. Illustrate these characteristics by reference to (a) typical animals, (*b*) typical plants. (C.S.C.)

67. What are the differences between animals and plants ? (O.&C.S.C.)

68. What effect do green plants have upon the atmosphere ? Describe *two* experiments which you could do to illustrate your answer. (O.S.C.)

69. Show in detail how you could isolate some oxygen from the atmosphere. Write a brief account of the relation of atmospheric oxygen to the life of plants. (O.S.C.)

70. What are the normal requirements of the leaf for the manufacture of starch ? Carefully describe *one* experiment showing clearly what happens in the absence of *one* of these requirements. What control experiment would you perform? (C.S.C.)

71. What are the most abundant food substances in (1) meat, (2) butter, and (3) bread ; and how are these substances changed by digestion ? (O.&C.S.C.)

72. What is respiration, and how is it carried out in animals and plants respectively ? (O.&C.S.C.)

73. Explain the terms asexual, sexual, and vegetative, as applied to reproduction in plants, and give *one* example of each. (C.W.B.S C.)

74. What conditions are essential for the healthy germination of seeds ? Describe *one* experiment to illustrate *each* condition named. (O.S.C.)

75. Describe a typical bean seed. Explain what happens when the seed germinates. (C.W.B.S.C.)

76. Describe and illustrate by a series of drawings the stages in the germination of any *one* seed. Explain how the seedling obtains its food during the early stages of germination. (O.S.C.)

77. Describe the structure of the stem of a plant and say what the various parts of the stem are used for in the life of the plant. (O.&C.S.C.)

78. Of what value to a plant is its flower ? Illustrate your answer by reference to the detailed structure of *one* named flower and to the functions of its various parts. (C.S.C.)

79. For what purposes do plants store food ? Mention the various parts used by plants for such storage, in the case of each part giving an example and making a sketch. (O.S.C.)

80. Name the structures which are *essential* to reproduction in animals. Compare the method of reproduction in Hydra and in any vertebrate animal. (L.G.S.)

81. Describe with the aid of drawings (*a*) the external features, (*b*) the modes of locomotion of an earthworm and of any *one* named insect. (C.S.C.)

82. Write an account of the life-history and habits of some invertebrate animal with which you are familiar. (O.S.C.)

83. Draw the young stage of a fly. How does it turn into the adult insect ? (O.&C.S.C.)

84. Name *three* different kinds of insects which are of economic importance, and in each case give reasons for considering the insect economically important. Explain with the aid of outline drawings how you would identify *one* of these insects in the adult stage. (C.S.C.)

85. Compare (*a*) a tadpole with a caterpillar, (*b*) a frog with a butterfly. (O.S.C.)

86. Describe some animal with which you are familiar (other than a frog, toad, butterfly, or moth), and point out the ways in which it is particularly adapted for its mode of life. (O.S.C.)

87. Give a careful account with illustrative drawings of the external appearance of *one* named fish. Briefly explain (*a*) how the fish obtains oxygen, (*b*) how it is able to swim, (*c*) how it feeds. (C.S.C.)

88. Draw a diagram of a typical limb of a land-living vertebrate animal. What departures are there from this type ? (O.&C.S.C.)

99. On what grounds would you classify a fish, a frog, and a snake in different groups ? Describe the structure of *one* of these animals. (O.S.C.)

90 To what extent do (*a*) plants depend upon animals, (*b*) animals depend upon plants, (*c*) animals depend upon animals for their nutrition ? Give definite examples. (C.S.C.)

91. Make drawings to show the appearance and relative positions of the following organs as seen in a dissection of a frog: stomach, heart, kidneys, fat body, ovaries (or testes). What is the main function of the kidneys? (C.S.C.)

92. Explain the meaning of *four* of the following terms: (1) Antenna, (2) Cotyledon, (3) Fertilization of an egg, (4) Nectar, (5) Pepsin, (6) Stoma, (7) Testis. (O.&C.S.C.)

PHYSIOLOGY

93. Show, by means of a drawing, the bones of the human shoulder and arm, and the mode of action of the biceps muscle. (O.&C.S.C.)

94. Show, by means of a rough labelled diagram, the principal parts of which the human nervous system is made up, indicating how these parts are connected.

Explain the functions of motor and sensory nerves. (C.W.B.S.C.)

95. Give an account of the functions of the red and the white blood corpuscles. What other functions does the blood perform? (C.S.C.)

96. What is meant by the digestion of food? Give a general account of the changes that food materials undergo during digestion. (C.S.C.)

97. In what way do bacteria cause disease, and how can the attacks of bacteria be checked or prevented? (O.&C.S.C.)

98. Explain various ways in which diseases may spread in untidy and unclean places. What steps can a householder take to help in maintaining the health of the community in which he lives? (C.S.C.)

INDEX

Accumulator, 130
Acids, 181, 228.
Acoustics, 95
Aeroplane, 18
Air, for ventilation, 77 ; properties of, 175 ; composition of, 178 ; humidity of, 190
Airship, 41
Albumen, or white of egg, 168, 319
Algae, 278
Alkalis, 181, 232
Allantois, 319
Alloys, 213
Aluminium, 147
Ammeter, 127 ; use of, 137
Amoeba, 291
Ampere, definition of, 126
Amphibians, 308
Antennae, 299
Anther, 273
Antiseptics, 238
Anus, 297
Aorta, 332
Archimedes, Principle of, 37
Arteries, 330, 332.
Arthropods, 298
Atoms, 143, 161, 204
Auricle, 316, 321, 330
Avogadro, 208

Bacteria, 76, 241, 278, 285
Ball bearings, 30
Barograph, 46
Barometer, simple, 45 ; aneroid, 46
Bean, 260
Bell, electric, 122
Benzine, 221
Birds, 308
Bladder, 339
Bleaching, 237
Board of Trade unit, 136
Boiling point, of water, 52 ; of water and salt solution, 63 ; variation with pressure, 64
Brain, 307, 329
Breezes, land and sea, 73
Bricks, 226
Bronchi, 334
Bryophyta, 278, 286
Budding, 255
Burning, 176
Buttercup, 260, 272
Butterflies, 304

Calcium carbide, 143
Calcium carbonate, causing hardness of water, 197 ; limestone, 223
Camera, 106
Capillarity, 170
Carbohydrates, 245, 249
Carbon, 216
Carbon dioxide, in breathing, 76, 333 ; solution in water, 166 ; use by plants, 184 ; preparation of, 185 , in natural waters, 197 ; test for limestone, 224 ; given off by seeds, 251
Carborundum, 142
Carpels, 274
Carpet-sweeper, 30
Cartilage 323
Cathode rays, 157
Cells, Leclanché, 129 ; dry, 130 ; guard cells, 247
Cellulose, 249
Central Electricity Board, 128

Central heating, 81
Chalazae, 319
Changes, physical and chemical, 162
Chlorine, 236
Chlorophyll, 240
Chloroplasts, 248
Chrysalis, 303
Chyme, 338
Cilia, 317
Cinema, 109
Circulation of blood, 332
Clays, 225
Clocks, 16
Clouds, 188
Coal, 217
Coal-gas, 218
Cohesion, 35
Colour, 111; by artificial light, 113; in nature, 113
Comets, 4
Compass, 118; pocket, 119; liquid, 119; gyro, 119
Compound, 143, 161; formulae of, 208
Conduction, of heat, 74
Conductors, of electricity, 128; experiment on, 150; lightning, 155
Convection, in air, 73; in water, 71
Copernicus, 1
Corolla, 272
Corpuscles, of blood, 333
Cotyledons, 262
Coulomb, 126
Critical angle, 99
Crop, 322
Crystaloid, 169
Cytoplasm, 291

Darwin, Charles, 258
Day, sidereal, 13; solar, 13
Density, 35; relative, 36
Dew, 187
Dialyser, 169
Digestion, 335
Disinfectants, 238
Dissociation, electrical, 144
Distillation, 165; fractional, 221
Duodenum, 337
Dynamo, 132

Earth, 3
Earthworm, 295
Echoes, 95
Eclipses, of moon, 90; of sun, 90
Efficiency, of electric lamps, 142; of machines, 30
Egg, 245; of fowl, 319
Elasticity, 34
Elaters, 287
Electric power, 135
Electrodes, 144
Electrolysis, 144
Electrolyte, 144
Electrons, 157
Electroplating, 144
Electroscope, gold leaf, 150; pith-ball, 149
Electrostatic induction, 151
Electro-typing, 146
Element, 143, 161, 205
Embryo, 256, 318
Emulsion, 168
Endosperm, 262
Energy, forms of, 31; heat as, 50
Environment, 256
Equations, chemical, 209
Escapement, of clock, 16
Evaporation, cooling effect of, 65; of solution, 163
Evolution, 257
Excretion, 254, 338
Expansion, of solids, liquids and gases, 50, 51
Eye, 107

Fats, 245
Femur, of frog, 315; of man, 324
Fermentation, 255
Ferns, 288
Fertilisation, 256
Filtrate, 163
Fins, 309
Fires, coal, 79; electric, 81; gas 80

Fish, 308; bony fish, 310; dogfish, 309
Fission, 255
Flagella, of bacteria, 285; of hydra, 294
Flotation, 39
Flowers, 260
Foot-candle, 87
Force, 17; parallelogram of, 18
Formulae, chemical, 208
Fowl, 309
Franklin, 149
Friction, 28; electrification by, 148; rolling, 29; sliding, 29
Frog, 309, 311
Fruits, 276
Fuels, 217
Fungi, 283
Furnace, electric, 142

Galactic Universe, 6
Galileo, 3
Galvanometer, 125
Gametes, 256
Gastric juice, 337
Gay-Lussac, 208
Gels, 168
Germination, 263
Gilbert, 148
Gizzard, 322
Glaciers, 62
Glands, sweat, 340
Glare, 94, 141
Glass, 226
Gravitation, 8
Gravity, centre of, 19

Haemoglobin, 254, 333
Hardness of water, 198
Heart, of frog, 316; of fowl, 321; of man, 331
Heat, as energy, 50; latent heat, 65; measurement of, 58; specific heat, 59
Hepidoptera, 305
Heredity, 257
Hermaphrodite, 256
Hibernation, 311
Honey-bee, 301
Horse-power, 28
Hot-water system, 72
House-fly, 299
Humerus, of frog, 314; of man, 324
Humidity, of air, in ventilation, 77; measurement of, 190
Hydra, 293
Hydrogen, 145; preparation and properties of, 193
Hygiene, 340
Hymenoptera, 304
Hypermetropia, 110
Hyphae, 283

Image, in a plane mirror, 92; lateral inversion of, 93; formed by lenses, 103
Insects, 299
Insulators, 128; experiment on, 150
Intestines, of frog, 317; of fowl, 322; of man, 336
Ions, 144
Iron, in mixtures and compounds, 162; rusting of, 174; smelting of, 214

Joints, ball and socket, 325
Jupiter, 3

Kaolin, 225
Kidneys, 254, 339
Kilogram, 13

Laws, chemical, 206
Leaves, 269.
Lenses, 101; focal length of, 102; formation of images by, 103
Lever, 22
Ligaments, 323
Light, intensity of, 86; nature of, 83; rectilinear propagation of, 88; speed of, 85
Light-years, 5
Lime, 201, 223

Liver, of frog, 317; of fowl, 322; of man, 338
Liverworts, 287
Lodestone, 116
Lungs, of frog, 316; of fowl, 322; of man, 334
Lymph, 334

Machines, 21; efficiency of, 31; mechanical advantage of, 31.
Magnesium, burning of, 176; magnesium sulphate, 235
Magnets, 116; electro-magnets, 121; magnetic field, 120; magnetic induction, 117
Mammals, 308
Mars, 3
Mass, 10
Matter, composition of, 143, 161; forms of, 33; indestructibility of, 206; living and non-living, 243; nature of, 204; properties of, 33.
Melting point, 60; variation with pressure, 61
Mendel, Gregor, 259
Mercury, 3
Meridian, of observer, 13; geographic, 118; magnetic, 118
Metals, ores of, 212; properties of, 211
Metamorphosis, 300
Meteor, 4
Metre, electric, 136
Micropyle, 260
Milky Way, 5
Mincer, 27
Mirage, 100
Mixtures, 161
Molecule, 143, 206
Moon, 9
Mosquitoes, 301
Mosses, 286
Moths, 304
Motor, electric, 127
Muscle, 315, 325
Mushroom, 283
Myopia, 111

Nebulae, 6
Neon tubes, 157
Neptune, 3
Nervous system, of earthworm, 296; of frog, 315; of man, 326
Newton, Sir Isaac, 7, 111
Nitrates, 239, 241
Nitrogen, 183; nitrogen cycle, 241
Nodes, 267
Nucleus, of atom, 204; of cell, 291
Nutrition, 243, 251, 335

Oesophagus, 337
Ohm's Law, 128; experiment on, 137
Oils, 221
Organs, of plant, 260
Organisms, 243
Osmosis, 169
Ovary, 273
Ovum, 256
Oxides, 181
Oxygen, 145, 179, 209, 244, 333

Pancreas, of frog, 317; of fowl, 322; of man, 338
Paraffin, 221
Peat, 217
Pelvic girdle, of frog, 315; of man, 324
Pendulum, simple, 14
Penumbra, 89
Pepsin, 337
Peptones, 338
Perianth, 273
Petrol, 221
Phosphorus, burning of, 177
Photography, 106; infra-red, 114
Photosynthesis, 248
Planets, 3
Plimsoll line, 40
Plumule, 262
Pluto, 3
Pole-star, 5
Pollen, 256, 273
Pollination, 274
Potato, 269

Potential, electric, 152
Pound, Imperial Standard avoirdupois, 13
Pressure, in liquids, 41 ; of air, 44
Prisms, refraction of light by, 101
Proteins, 245
Protococcus, 279
Protoplasm, 245
Proventiculus, 322
Pseudopodia, 291
Pteridophyta, 278
Ptyalin, 337
Pulley, 27
Pump, common, 48
Pupae, 300

Radiation, of heat, 69
Radicle, 262
Radio-ulna, of frog, 314
Radius, 324
Rainbow, 115
Rectum, 337
Reflection, of light and sound, 90 ; laws of, 92 , diffused, 93 ; total, 99
Refraction, of light, 97 ; index of, 98
Refrigerator, 66
Rennin, 337
Reproduction, 244, 255
Reptiles, 308
Resistance, electric, 128 ; experiment on, 137
Respiration, 243 ; in animals, 253 ; in plants, 250
Rhizomes, 268
Rigidity, 34
Röntgen, 158
Root-hair, 169, 246
Root pressure, 247
Roots, 264
Rusting, of iron, 174 ; prevention of, 182

Saliva, 337
Salt, common, 234
Sand, 226
Saturn, 3
Scapulae, of frog, 314 ; of man, 324
Sea-anemones, 295
Sea-weed, 282
Seeds, 260 ; dispersal of, 277
Setae, 297
Shadows, 88
Shooting star, 4
Silica, 226
Silkworm, 306
Sinovial fluid, 324
Siphon, 49
Skeleton, of fish, 310 ; of frog, 314 ; of fowl, 321 ; of man, 324
Soap, 233
Soda, caustic, 232 ; washing, 164, 200
Solar system, 3
Solute, 163
Solution, 163 ; colloidal, 168 ; separation by, 165
Solvent, 163
Sound, nature of, 83 ; intensity of, 86 ; speed of, 85
Specific gravity, 36
Spectacles, 110
Spectrum, 111
Sperm, 245
Sphincter, 337
Spinal cord, 307, 329
Spirogyra, 278, 279, 281
Spores, 283
Spring balance, 12
Stability, 21
Stalactites, 203
Stalagmites, 203
Stamens, 273
Starch, solubility of, 164 ; as carbohydrate, 248
Stars, 4
Stem, 267
Sternum, of frog, 314 ; of fowl, 321 ; of man, 324
Stigma, 273
Stomata, 247
Sugar, 248
Sulphur, in mixtures and compounds, 162 ; compounds in coal gas, 219
Surface tension, 171

Suspension, of particles in solution, 163; a suspension, 168
Symbols, chemical, 207

Tadpole, 313
Telephone, 123
Temperature, definition of, 57
Tendons, 325
Testa, 260
Testis, 295
Thallophyta, 278
Thermometers, 52; clinical, 53; fixed points of, 53; maximum and minimum, 54; wet and dry bulb, 190
Thunderstorms, 85, 153
Tibio-fibula, of frog, 315
Tides, 8
Tobin Tube, air inlet, 78
Tracheae, 300, 334
Transpiration, 247
Tropism, 257

Ulna, 324
Umbra, 89
Uranus, 3
Ureter, 339
Urine, 255, 339

Vaccination, 341
Vacuum cleaner, 127
Variations, 258
Veins, 330, 332
Ventilation, 75
Ventricle, 316, 321, 330
Venus, 3
Vertebrae, of frog, 314; of man, 324
Vertebrates, 290, 307; development of, 322
Vitamins, 252, 337

Wallflower, 275
Water, composition of, 195; freezing and boiling points, 52; formula of, 209; hardness of, 198; maximum density of, 55; natural waters, 197; properties of, 192
Water softeners, 202
Water-supply, principle of, 43, 340
Watts, 134
Weather, 46
Weight, 11
Wheat, 260
Winch, 26
Work, 23

X-rays, 158

Zygote, 256

PRINTED IN GREAT BRITAIN BY ROBERT MACLEHOSE AND CO. LTD.
THE UNIVERSITY PRESS, GLASGOW